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MULTI-SITE INTERROGATION SCHEDULING FOR THE DISCRETE ADDRESS BEACON SYSTEM

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16. Abstract

A theoretical analysis and computer simulation were undertaken to develop a DABS/ATCRBS scheduling algorithm which would be capable of servicing the projected 1995 Los Angeles Basin (1608 aircraft aloft). A satisfactory technique was found using sub-epoch timing, partitioning between packed and synchro calls, and time-sharing (a separate interval for each site's synchro calls). The technique also provides garble-free Synchro DABS (air-to-air CAS) service in the multi-site DABS/ATCRBS environment. Time is provided during the packed call interval for extended length messages and target reinterrogation.

In order to achieve these results, the ATCRBS PRF was reduced to 150 (7 hits/scan), but high uplink reliability was introduced by using time synchronization of ATCRBS sites with the firing time of each site calculated as a function of antenna azimuth. This eliminates ATCRBS transponder suppression due to asynchronous multiple site interrogations.

The scheduling algorithm was verified by analysis and computer simulation to service the 1995 LA Basin with both a 4 DABS/8 ATCRBS site model and an 8 DABS/8 ATCRBS site model, even with the failure of one DABS site in either case.

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I. INTRODUCTION

The Discrete Address Beacon System (DABS) has been designed to provide both a surveillance and communication capability in the ATC system. Surveillance performance will be improved by comparison with today's ATCRBS system, and the data link communication will provide the means by which many ATC services can be automated (Intermittent Positive Control, Metering and Spacing, etc.). A functional block diagram of the DABS sensor is presented in Figure I-1.

This report specifically treats the interrogation scheduling task which is part of the channel management function illustrated in Figure I-1.[1] A method for performing DABS interrogation scheduling in a multi-sensor, DABS/ATCRBS environment has been derived and is described in detail in this report. The technique will additionally accommodate an air-to-air mode of collision avoidance known as Synchro DABS.[2] In this effort, Synchro DABS was designed to be completely free of air-to-air garble.

The algorithms contained in this report pertaining to DABS, Synchro DABS, and ATCRBS are to be implemented and tested at the National Aviation Facilities Experimental Center in the DABS experiments. Algorithms which have been demonstrated to be functionally equivalent are also acceptable.

A summary follows of the DABS multi-site interrogation scheduling techniques developed by the authors:

The cycle length (repetition period) is 13 1/3 ms and consists of the following separate intervals:

1. One packed call interval for DABS surveillance and data link communications including any extended length messages. No Synchro DABS CAS is conducted during the packed call due to the presence of air-to-air garble. All DABS sites use the same packed call interval.

2. One separate synchro call interval for each DABS site. (Four and eight site models have been used for the LA Basin.) A sub-epoch timing scheme is used in conjunction with an "expanding-ring" type schedule in order to insure

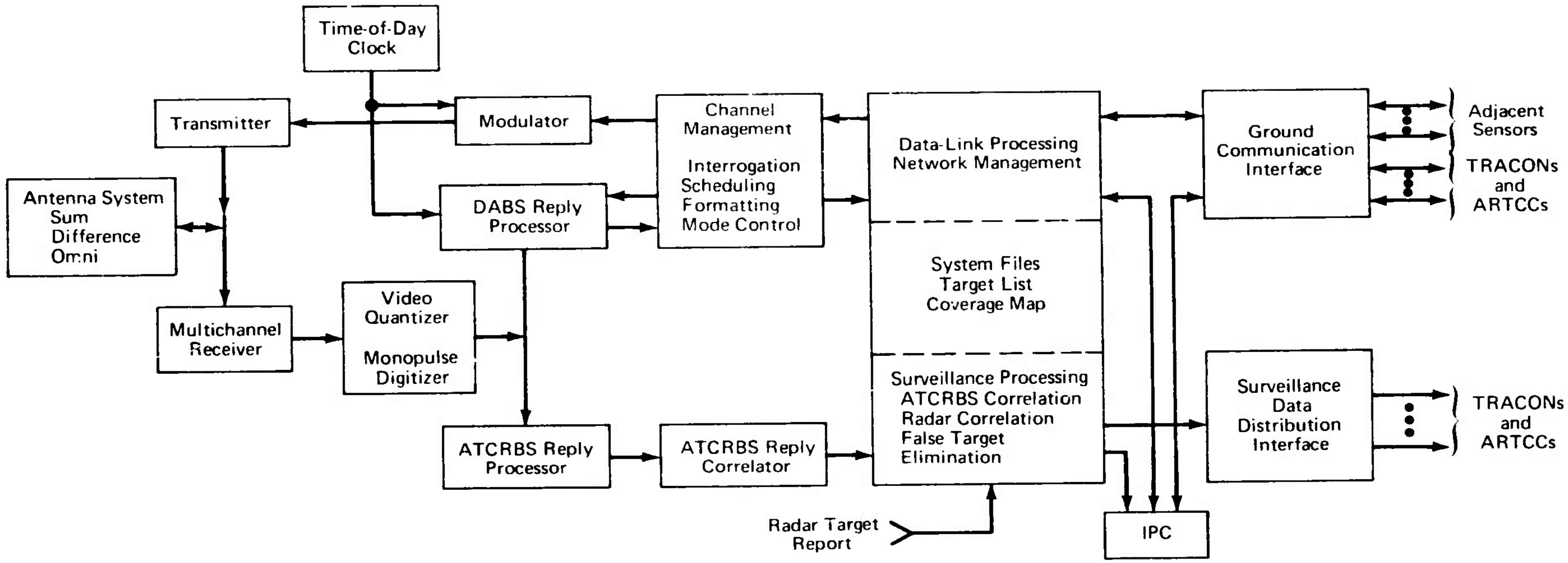


Figure I-1. DABS SENSOR FUNCTIONAL BLOCK DIAGRAM

that all Synchro DABS equipped aircraft will receive completely garble-free the transmissions of all other aircraft within a 20 n.m. radius. In order to achieve this goal with the 1995 LA Basin traffic model, it was necessary to delete scheduling reception of aircraft transmissions at the DABS antenna; thus, no surveillance is accomplished during the synchro calls.

3. Two separate ATCRBS intervals, each combined with a DABS general call. Two such ATCRBS interrogations during each 13 1/3 ms cycle result in an ATCRBS PRF of 150 per second (7 hits per scan). This decrease from the present PRF (300-400) is partially compensated by introducing high uplink reliability using time synchronization of ATCRBS sites with the firing time of each site calculated as a function of antenna azimuth. The method eliminates ATCRBS transponder suppression due to asynchronous multiple site interrogations.

This DABS interrogation scheduling algorithm was tested in a computer simulation. The 1995 LA Basin traffic model was used with an 8 DABS site model, a 4 site model, and the 4 site model failure mode (one site failed). Successful results were obtained in all cases, i.e., all aircraft were scheduled in the allotted times. Analysis was also used to obtain worst-case scheduling time requirements and to provide an additional cross-check of the scheduling technique.

This report is organized in the following manner. Chapter 2 treats the overall scheduling problem in a multi-site DABS/ATCRBS environment. Chapter 3 deals with single site DABS interrogation scheduling and presents the results of the scheduling simulation. Chapter 4 discusses the failure mode simulation where one DABS site is assumed to have failed and the other sites are reconfigured to handle the traffic. A brief summary of the work and conclusions are contained in Chapter 5. The appendices contain supporting analysis, detailed scheduling algorithm flow charts, and FORTRAN program listings.

II. MULTI-SITE INTERROGATION SCHEDULING

The prime objective of multi-site interrogation scheduling is to assign time on the antenna for making DABS calls to and receiving replies from equipped targets and for conducting ATCRBS interrogations and receptions. A specific algorithm for accomplishing this objective with a single site is presented in Chapter 3 and detailed further in Appendix A. The present chapter, however, treats the problem in a multi-site DABS/ATCRBS environment. In this multi-site environment the major problem which must be solved is that of interference. DABS and ATCRBS will both use the same frequencies for transmitting and receiving respectively. Ground-to-air or uplink transmissions will be at 1030 MHz while air-to-ground and air-to-air transmissions will be at 1090 MHz.

Interference between DABS and ATCRBS is therefore inevitable unless time is specifically allocated for separate DABS/ATCRBS operations. This then implies the requirement for time-synchronization of sensor sites. In addition, the time allocated for each mode of operation must be sufficient to accommodate both the required sensor range and the number of targets to be serviced.

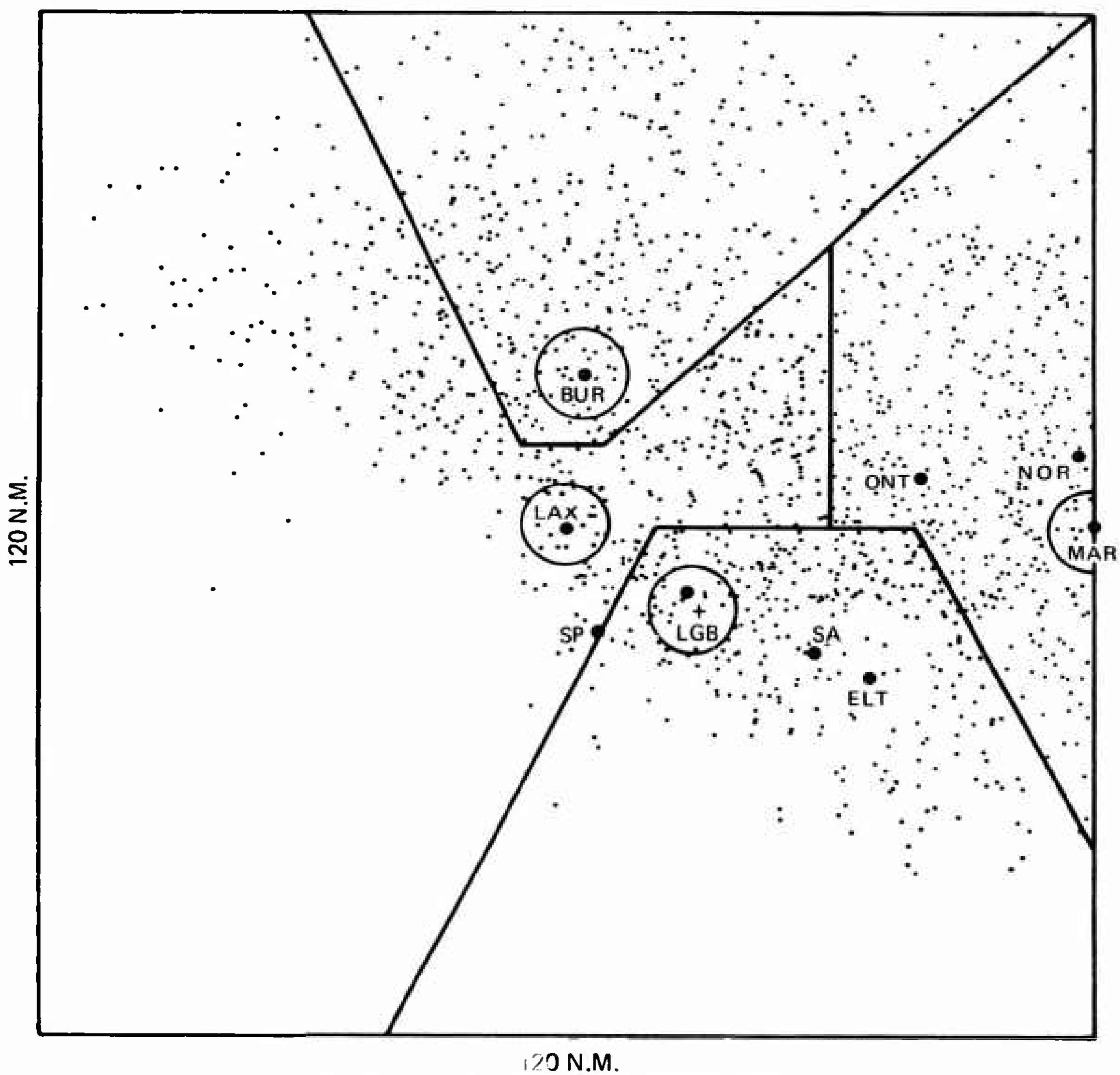
The basic system parameters associated with the determination of the DABS and ATCRBS time allocations are: radar range, number of targets, antenna rotation rate, beamwidth, cycle time, message length, and pulse repetition frequency (PRF). The values used in this report for these parameters are listed in Table II-1 and are consistent with the overall system design (Ref. 1).

TABLE II-1

SYSTEM PARAMETERS

Parameter	Value
Range	60 n.m. (terminal), 100 n.m. (enroute) 65 n.m. (zenith overlook)
Number of targets	LAX 1995 model (1608 aircraft)
Antenna Rot. Rate	90°/sec.
ATCRBS Beamwidth	4.2°
DABS Beamwidth	2.4°
DABS Slice Width	1.2° (300 slices/scan)
ATCRBS PRF	150 (7 Hits/Tgt. - Mode A/C)
DABS PRF	75/sec.
Synchro DABS PRF	75 sec./site
Cycle Time	13 1/3 ms
DABS Message Time	
Synchro Call	Uplink 36 μs; downlink 36 μs
Packed Call	Uplink 36 μs; downlink 64 μs
ATCRBS Message Time	Call 25 μs; reply 25 μs
DABS Transponder Delay	128 μs (Measured from leading edge of interrogation to leading edge of reply)

These parameters are used in conjunction with the 1995 LA Basin model illustrated as Figure II-1 (Reference 3).



SITE	NUMBER OF AIRCRAFT	COORD (n.m.) N	E
LAX	424	0	0
MAR	447	0	60
BUR	403	15.02	2.68
LGB	331	-8.08	13.44

ZENITH OVERLOOK PAIRS:
LAX AND MAR
BUR AND LGB

ZENITH RADIUS 5 n.m.

Figure II-1. L.A. Basin Model (1995) 1605 Targets

II. 1 ATCRBS TIMING

The proposed DABS/ATCRBS multi-site schedule includes two ATCRBS intervals in each 13 1/3 ms cycle, giving an ATCRBS PRF of 150. Since this is a reduction from the present PRF range of 300-400, a study was undertaken to devise a means of compensation for the decreased PRF through increased round reliability. At present in high density areas, a major reason for loss of round reliability is ATCRBS transponder suppression due to asynchronous multiple site interrogations. This is due to three sources: interfering side lobe suppression, unwanted suppression due to overlooking sites, and Mode C to A conversion by "stray" P_1 pulses. (A full explanation is presented in References 5 and 6.)

These three causes for loss of round reliability (loss of uplink reliability, to be more precise) can be eliminated by an ATCRBS firing time scheduling algorithm, which requires time sychronization of ATCRBS sites. Actually, two such algorithms were devised: one which also requires interrogator antenna azimuth synchronization and one which does not. They are described in Appendices C and B, respectively. In either case, control of ATCRBS firing times serves to eliminate unwanted suppression of airborne transponders, thus increasing uplink reliability. If there were no airborne antenna shielding (by the wings or fuselage), suppression due to DME pulses, or ground antenna pattern nulls, etc., the theoretical round reliability would be 100% using either method. In the remainder of the report, this effect has been termed "high uplink reliability."

It should be noted that such methods involving time synchronization of ATCRBS sites and controlled ATCRBS firing times may only be necessary in high density areas. (High density in this case refers to a high density of ATCRBS interrogators--not aircraft.)

The design with antenna azimuth synchronization is described in Appendix C, which is a summary of Reference 5. Figure II-2 shows the schedule time which is required to achieve zero site-to-site interference as a function of azimuth. The maximum schedule time ever required is seen to be about 750 μs. An additional consideration is that a number of sites other than the eight considered are peripheral to the region of interest. As a

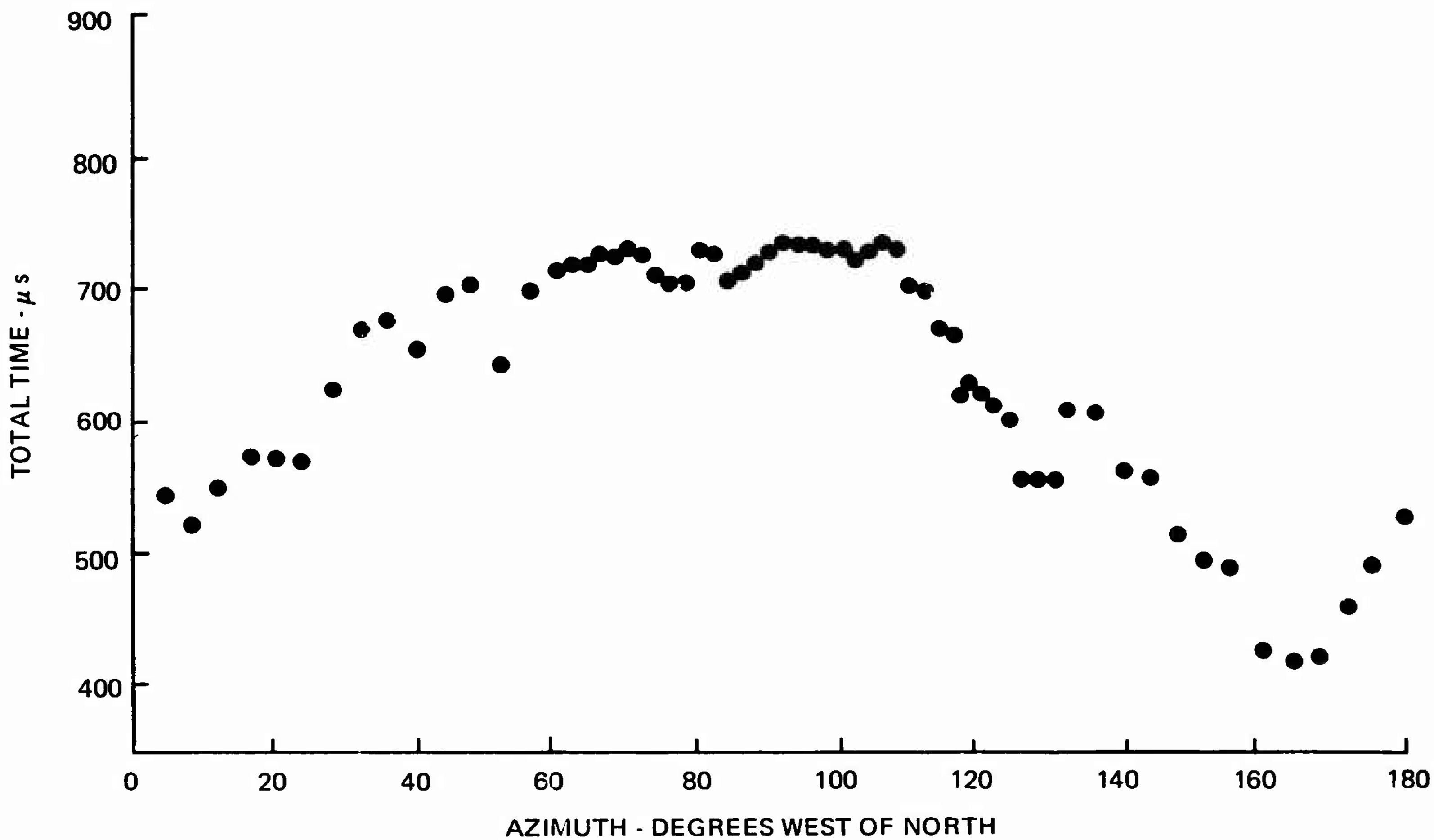


Figure II-2. Total ATCRBS Firing Time For The L.A. Basin

result, it is anticipated that an additional 100 μs could be required to achieve a totally interference-free ATCRBS environment. Thus, the time required for an ATCRBS interval is 850 μs for scheduling plus 800 μs for the last call/reply to go out 60 n.m. and back, for a total of 1650 μs. For the enroute case 1300 μs is required for the call/reply interval leaving 350 μs for scheduling the enroute radars, which should be adequate since their smaller numbers and larger intersite separations makes their interaction small relative to the terminal sensors.

The design without antenna azimuth synchronization is described in Appendix B. There it is shown that 1404 μs is the maximum time required to schedule all 8 ATCRBS sites to fire once with high uplink reliability. An additional 800 μs is added to allow the last interrogation to travel to an aircraft 60 n.m. away, then allow that aircraft's response to return to the antenna. Thus, each of the two ATCRBS intervals will have a duration of 2200 μs. The unsynchronized and, therefore, simpler method was chosen. Although it required more schedule time for ATCRBS, this time could in fact be made available without significantly degrading DABS performance. In the remainder of this report, unsynchronized antenna azimuth is assumed unless otherwise noted.

II.2 DABS TIMING

The multi-site DABS/ATCRBS 13 1/3 ms cycle was described qualitatively in Chapter I, and Section II.1 established the ATCRBS interval at 2200 μs.* The remainder of this chapter will deal with establishing the length of the packed call and synchro call intervals for both the 4 and 8 site cases.

In the multi-site environment, a potential problem of air-to-air garble in the Synchro DABS mode arises if adjacent DABS sites call nearby aircraft with synchro calls simultaneously. Note that this problem of air-to-air garble could also arise for aircraft under control of a single site, but this is avoided by scheduling the targets in decreasing range order and then letting the i^{th} aircraft's pulse train pass the $i+1^{st}$ aircraft before the $i+1^{st}$ aircraft begins its

* Note that the DABS General Call is conducted during the so-called ATCRBS interval (see Chapter I).

transmission ("expanding-ring" concept). To eliminate air-to-air garble in the multi-site environment, a time-shared technique can be employed such that each site has a specific time for making synchro calls and will be silent while the other sites are making synchro calls. An analysis of the air-to-air garble problem is presented as Appendix E of this report. The result of this analysis indicates that a garble-free zone of 20 n.m. around each potentially interacting aircraft can be achieved if a buffer of 50 μs between synchro calls is allowed (between sites). A 12 n.m. garble-free zone is achieved with no buffer if the reply of the last aircraft to be called by one site is allowed to clear that site's antenna before the next site begins its synchro calls. (This requirement has been met, as described in the paragraph following Equation 2, below.)

It has been shown analytically in Appendix D that the maximum time required to schedule N targets in one slice using the scheduler described in Appendix A is:

$$T_{S_{max}} = (2N-1)\tau_R + N\tau_I + (N-1)\tau_B + T_D + \frac{2}{c} r_1 \qquad (1)$$

for the packed call and synchro call with reply scheduling.* (All symbols in the above equation are defined in Appendix A, and numerical values are given in Table A-1.) In simulations the above equation proved to be quite conservative for N on the order of 10 targets or more. For the synchro call without reply scheduling, the maximum schedule time is:

$$T_{S_{max}} = N(\tau_R + \tau_B) - \tau_B + \tau_I + T_D + \frac{2}{c} r_1 \qquad (2)$$

Although Equation 2 applies to the case where replies are not scheduled for reception at the DABS antenna, Equation 2 does allow time for the last aircraft reply to reach and clear the DABS antenna. This was done so that synchro call intervals from adjacent sites could be scheduled sequentially in time without a buffer between the two intervals--and without the last aircraft called by the first site garbling the first aircraft called by the second site.

* As stated in Chapter I, the synchro call with reply scheduling was abandoned in favor of the synchro call without reply scheduling due to the shorter schedule times of the latter.

II. 2. 1 FOUR SITE CASE

A computer simulation was conducted with DABS sites at Los Angeles, Burbank, Long Beach, and March. Intrasite boundaries were as shown in Figure II-1. Although four DABS sites were used, all eight ATCRBS sites were included in the LA Basin and the ATCRBS interval (2200 μs) was based on these eight sites (see Appendix B).

A computer study of the 1995 LA Basin Model (1608 aircraft - see Figure II-1) showed the maximum number of aircraft in any one slice(1.2^{o} slice width) to be 11. This value for N substituted into Equation 2, above, along with the system parameters of Table A-1, gives a maximum required synchro call schedule time of 1446 μs. Thus 4 times 1446 μs, or 5784 μs, is required for the 4 synchro calls. The packed call interval occupies what remains of the 13, 333 1/3 μs cycle length after the ATCRBS and synchro calls are subtracted out. This subtraction yields a packed call interval of 3149 1/3 μs. Equation 1, above, with N=11 gives a maximum theoretical packed call of 2754 μs. However, as will be seen in Chapter III, the maximum observed packed call schedule time for the 1995 L. A. Basin model simulation was 1980 μs. Thus, the allocated packed call interval is approximately 60% larger than the observed requirement. It is felt that this margin will be quite ample to accommodate reinterrogation of missed targets, extended length messages, and longer message types. This overall schedule for the 4 site case is shown in Figure II-3. Note that no buffer has been included between the 4 synchro call intervals; therefore, the minimum guaranteed garble-free zone radius around each aircraft in the Synchro DABS mode is 12 n. m., as discussed in the previous section and in Appendix E.

II. 2. 2 EIGHT SITE CASE

Eight DABS sites and their associated boundaries are shown in Figure II-4. This model was taken directly from a Lincoln Laboratory publication.[1] As seen in the figure the number of aircraft handled by each site ranged from 382 down to 27. Therefore, it was decided that synchro call interval lengths should vary between sites. (In the four site case, all sites had approximately the same number of aircraft. Thus, all four synchro call intervals were set equal. The common length was based on the busiest site.)

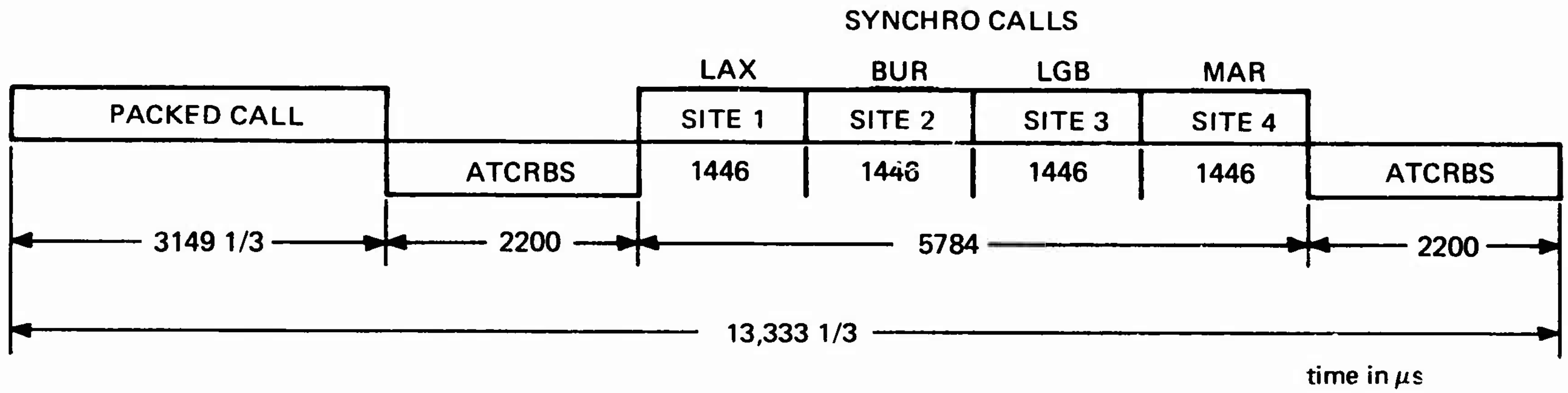
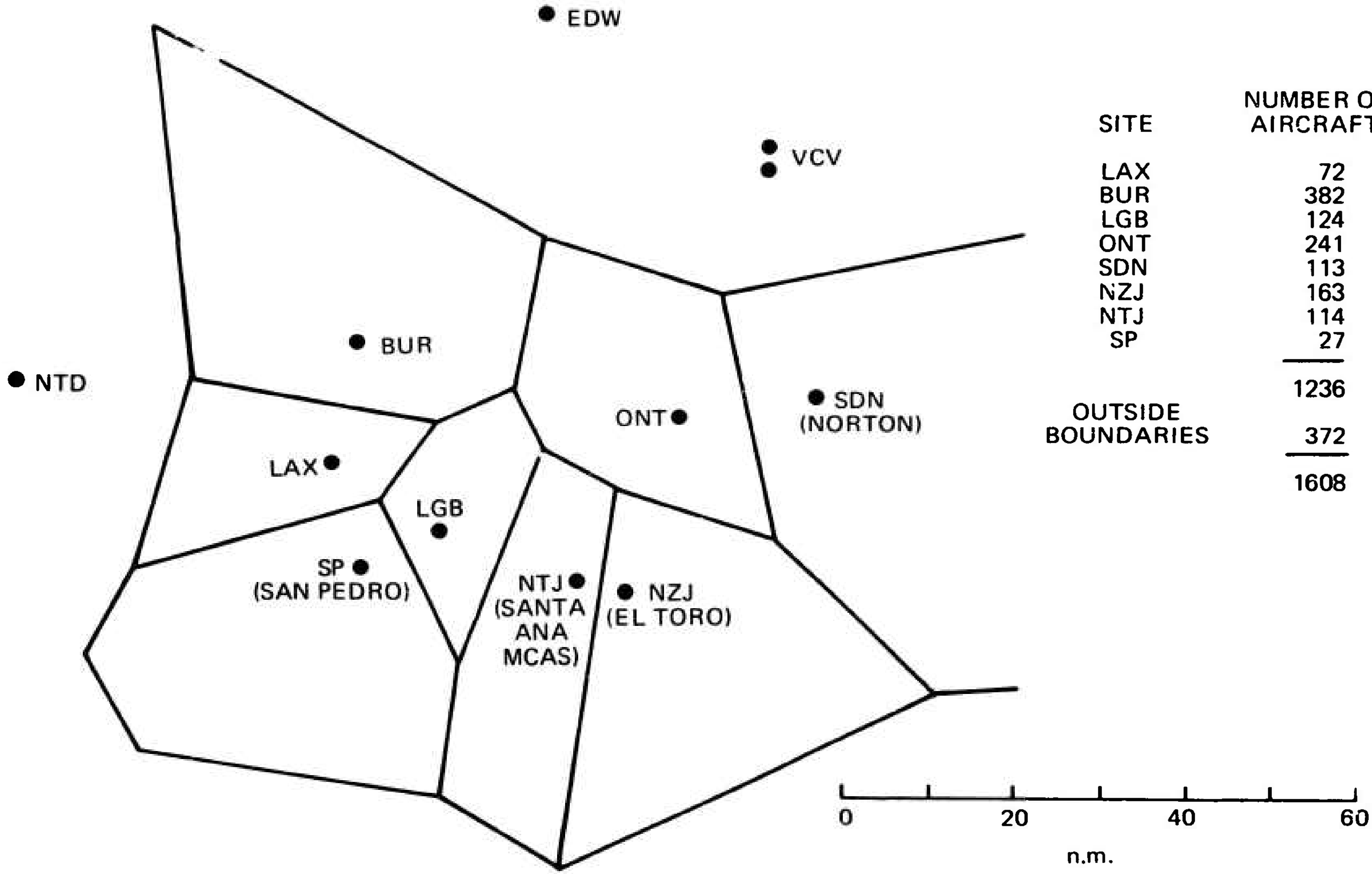


Figure II-3. Multi-Site Interrogation Schedule
(4 Site Model)



SITE	NUMBER OF AIRCRAFT
LAX	72
BUR	382
LGB	124
ONT	241
SDN	113
NZJ	163
NTJ	114
SP	27
	1236
OUTSIDE BOUNDARIES	372
	1608

Figure II-4. Eight Site Model

The eight site geometry and the 1995 LA Basin traffic model (1608 aircraft, Figure II-1) were input to the computer to determine N_{max}, the maximum number of targets per slice for each site. As in the four site case this number N_{max} was input into Equation 2 above to determine the maximum schedule time $T_{s\ max}$, required for the synchro call of each site. This calculation employed the same system parameters used by the four site case (Table A-1) except that the maximum target range, r_1 was decreased from 60 to 48 n.m. based on the eight site geometry. The results are shown in Table II-2.

Table II-2. Eight Site Synchro Call Schedule Times

Site	Maximum Aircraft/Slice N_{max}	Required Schedule Time $T_{s\ max}$ µs
LAX	5	973.3
BUR	7	1081.3
LGB	5	973.3
ONT	7	1081.3
NZJ	5	973.3
NTJ	4	919.3
SP	2	811.3
SDN	4	919.3

A further time savings can be obtained by noting on Figure II-4 that there are three pairs of sites which all have the following property: all points within the boundary of the first site are at least 20 n.m. from all points within the boundary of the second site. The three pairs are LAX and NZJ, BUR and SDN, SP and ONT. Since Synchro DABS airborne transponders will not be garbled by an aircraft more than 20 n.m. away when listening to an aircraft less than 10 n.m. away (using pulse amplitude modulation - PAM), it is therefore possible to conduct the synchro calls of both sites of a pair simultaneously without introducing detrimental air-to-air garble. Thus, the guaranteed minimum garble-free zone radius around each aircraft in the Synchro DABS mode is 10 n.m. for the eight site case. (In the last section, the figure was 12 n.m. for the four site case.)

The resulting eight site schedule is shown in Figure II-5. The synchro call interval lengths were taken from Table II-2, the ATCRBS interval lengths remain at 2200 μs, and the packed call occupies the remainder of the 13,333 1/3 μs cycle time, which is 3901 1/3 μs.

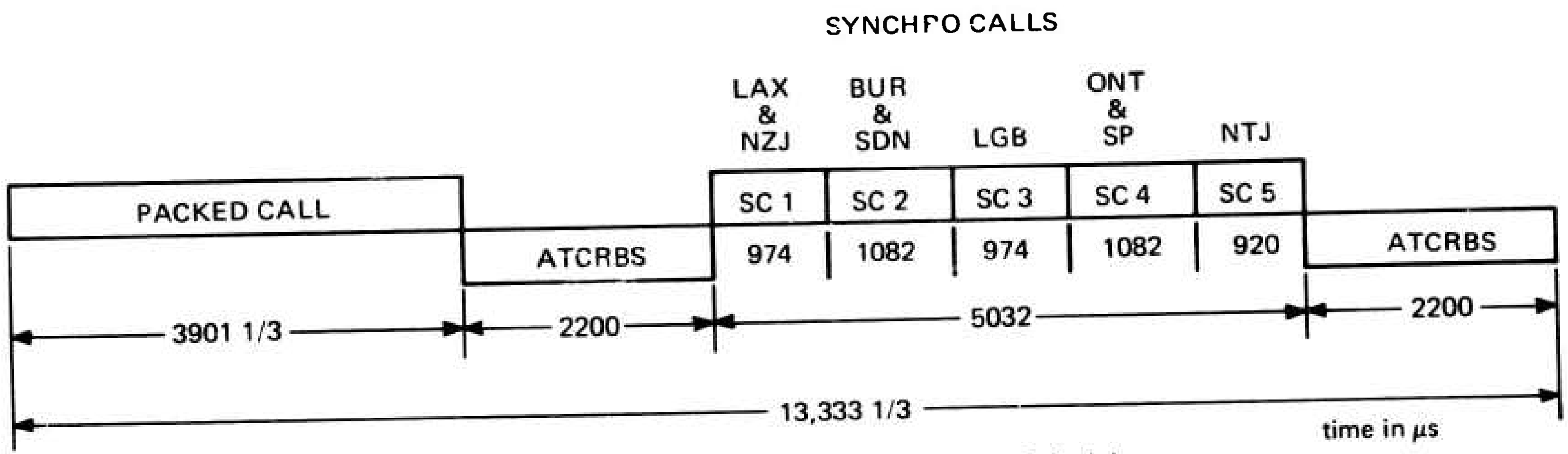


Figure II-5. Multi-Site Interrogation Schedule (8 Site Mode!)

III. SINGLE SITE INTERROGATION SCHEDULING

The objective of DABS single site interrogation scheduling is to efficiently reserve interrogation time and reply reception time at the DABS antenna for all targets such that:

- o No calls overlap other calls at the DABS antenna.
- o No replies overlap other replies at the DABS antenna. *
- o No calls overlap replies or vice versa at the DABS antenna. *
- o All aircraft reply sub-epochs are sufficiently spaced so as to insure (airborne) garble-free Synchro DABS operation. **

An algorithm has been formulated which will satisfy the above constraints and which has the attributes of low computation overhead plus a dynamic rescheduling capability. The algorithm is fundamentally a modification of the Lincoln Laboratory "DYNO" algorithm,[4] and utilizes sub-epoch timing for Synchro DABS scheduling.

An epoch timing algorithm for Synchro DABS scheduling has been tested. However, this technique (even when coupled with limited beam agility) does not have sufficient capacity to service the 1995 LA Basin and simultaneously provide air-to-air garble-free operation in the multi-site environment. The only potential solution to this problem would be off-loading of aircraft under the jurisdiction of one site to an adjacent site which was not busy at the time. This, however, would increase the communications load between sites. Also, it would be difficult to guarantee that an adjacent site would always have sufficient capacity to handle the additional load.

* During synchro calls aircraft replies are not scheduled for reception at the DABS antenna.

** True for synchro calls; not necessary for packed calls.

A single site scheduling technique which merges packed and synchro calls together in a single interval has also been proposed. This technique potentially has more capacity than the partitioned method developed here but does not have the air-to-air garble protection provided by the partitioned technique. Thus partitioned scheduling (separate packed and synchro calls) coupled with sub-epoch timing is recommended.

The scheduling algorithm is presented in Appendix A. A detailed flow chart and a FORTRAN listing with comment cards are given. For specified aircraft ranges within a slice, one run of the program produces the schedules for both the packed call and the synchro call (synchro call without reply scheduling). A schedule is also done for a synchro call with reply scheduling, although this is not recommended for use because of increased time requirements, as stated in Chapter I. This chapter presents the simulation results for the scheduling algorithm using the 1995 LA Basin traffic model (1608 aircraft). This is considered the worst-case traffic model for the DABS era.

III.1 SIMULATION RESULTS

The single-site scheduling algorithm presented in Appendix A has been simulated on a Hewlett-Packard 9810A calculator and on a CDC 6400 time sharing system. The basic algorithm requires approximately 1000 instructions to code in assembly language and about 400 words of memory, the major portion of which were used for bin assignments. The most heavily populated slices of all DABS sites in the LA Basin were scheduled using this simulation. The parameters which serve as input to the simulation (in addition to the target ranges) are given in Table A-1.

The results for packed call and Synchro DABS sub-epoch scheduling for the 4 site model are presented in Table III-1 (a-d). Only slices with 5 or more targets were scheduled for this case. These results are also presented in graphical form as Figure III-2. It should be noted in Figure III-2 that the theoretical worst-case schedule time as a function of the number of targets (derived in Appendix D) is presented graphically and is validated by the simulation results. In Figure III-2 the theoretical maximum schedule time was computed assuming a maximum range of 70 n.m., since there were some targets at this distance in the LA Basin model area. In actual operation the terminal DABS sensor range would be 60 n.m. The targets at greater distances would be handled by DABS sites outside the LA Basin. Therefore, the time allocations used (1446 μs) were based on a 60 n.m. range. Note that all 1200 slices in the LA Basin model could be scheduled within the 1446 μs interval.

Thus a high degree of confidence in both the simulation and analysis is established. The worst case (i.e., worst single slice) schedules for both synchro and packed calls are presented as Figure III-3 for purposes of illustration. Figure III-3(a), (b) are synchro call schedules and (c) is the packed call schedule for the 4 site model (for the system parameters specified in Appendix A). The simulation and analytical results for the 8 site case are summarized in Figure III-4 (a) and (b) and were used to establish the timing requirements specified in the previous chapter.

In summary, the single site algorithm presented will perform both packed call and synchro call scheduling, is highly efficient, and is capable of dynamically rescheduling targets in the event of a missed reply. Further, no air-to-air garble among aircraft scheduled by the algorithm for a single site is possible in the Synchro DABS mode.

TABLE III - 1 (a). LOB SCHEDULES

SLICE NUMBER	AZIMUTH	NUMBER OF TARGETS	SYNCHRO CALL (NOTE 1)	SYNCHRO CALL (NOTE 2)	PACKED CALL (NOTE 3)
62	74.40	6	1026.00	766.00	1134.00
69	82.80	11	1416.00	1062.00	1632.00
70	84.00	5	690.00	690.00	1032.00
71	85.20	7	1126.00	646.00	1260.00
73	87.60	7	1104.00	856.00	1236.00
83	99.60	5	964.00	786.00	1080.00
103	123.60	7	1296.00	1062.00	1344.00
113	135.60	5	1008.00	610.00	972.00
261	337.20	5	810.00	610.00	888.00
264	340.80	7	1126.00	906.00	1260.00

Note 1 Synchro call with all replies scheduled for garble-free reception at the DABS antenna. (This method is not recommended, as stated in the text.) $\tau_R = 36\ \mu s$.

Note 2 Synchro call without reply scheduling at the DABS antenna. Thus no surveillance is performed; only the Synchro DABS collision avoidance function is accomplished. Although replies may overlap at the DABS antenna, the schedule times shown do allow for all replies to clear the DABS antenna. This is to prevent the last replies to one site's synchro call from interfering with the first replies from the next site's synchro call (see Appendix E). (This type of synchro call is recommended in the text due to its shorter schedule times.) $\tau_R = 36\ \mu s$.

Note 3 Packed call with all replies scheduled for garble-free reception at the DABS antenna. Surveillance and data link are performed. Synchro DABS is not performed due to the existence of air-to-air garble. $\tau_R = 64\ \mu s$.

TABLE III - 1 (b). MAR SCHEDULES

SLICE NUMBER	AZIMUTH	NUMBER OF TARGETS	SYNCHRO CALL (NOTE 1)	SYNCHRO CALL (NOTE 2)	PACKED CALL (NOTE 3)
223	267.60	7	1560.00	1276.00	1410.00
224	268.80	5	1158.00	1158.00	1104.00
226	271.20	9	1660.00	1326.00	1560.00
227	272.40	10	1762.00	1440.00	1962.00
228	273.60	8	1458.00	1224.00	1050.00
232	278.40	8	1158.00	924.00	1332.00
233	279.60	7	1164.00	858.00	1296.00
240	288.00	5	774.00	774.00	852.00
241	289.20	5	762.00	762.00	840.00
242	290.40	6	1062.00	840.00	1194.00
243	291.60	6	1266.00	960.00	1434.00
250	300.00	5	1062.00	864.00	1170.00
251	301.20	6	1194.00	960.00	1326.00
253	303.60	5	750.00	750.00	1092.00
255	306.00	6	1074.00	676.00	1162.00
256	307.20	7	1248.00	930.00	1368.00
259	310.80	5	670.00	670.00	1236.00
267	320.40	5	930.00	930.00	1008.00
268	321.60	11	1572.00	1242.00	1740.00
270	324.00	6	972.00	972.00	1374.00
271	325.20	7	1236.00	918.00	1368.00
273	327.60	5	822.00	822.00	1176.00
274	328.80	7	1284.00	1038.00	1320.00
277	332.40	10	1566.00	1212.00	1950.00
280	336.00	7	1368.00	1062.00	1368.00
281	337.20	11	1596.00	1254.00	1960.00
282	338.40	8	900.00	900.00	1314.00
285	342.00	6	1026.00	840.00	1134.00
286	343.20	6	1146.00	864.00	1254.00
291	349.20	5	1026.00	1026.00	1128.00
292	350.40	7	1366.00	1098.00	1290.00
294	352.80	6	1098.00	876.00	1230.00
295	354.00	6	936.00	936.00	1026.00
298	357.60	7	1194.00	1194.00	1296.00

TABLE III - 1 (c). LAX SCHEDULES

SLICE NUMBER	AZIMUTH	NUMBER OF TARGETS	SYNCHRO CALL (NOTE 1)	SYNCHRO CALL (NOTE 2)	PACKED CALL (NOTE 3)
34	40.80	6	852.00	852.00	1302.00
35	42.00	5	858.00	858.00	1200.00
36	43.20	7	1050.00	1050.00	1536.00
39	46.80	5	906.00	906.00	720.00
43	51.60	7	1296.00	966.00	1428.00
44	52.80	8	1302.00	996.00	1368.00
45	54.00	5	738.00	738.00	1068.00
47	56.40	6	852.00	852.00	1302.00
48	57.60	6	876.00	876.00	966.00
49	58.80	6	876.00	876.00	966.00
50	60.00	7	1200.00	894.00	1320.00
55	66.00	6	780.00	780.00	870.00
57	68.40	7	882.00	882.00	1404.00
59	70.80	5	762.00	762.00	840.00
73	87.60	8	1506.00	1284.00	1386.00
75	90.00	10	1794.00	1404.00	1974.00
247	296.40	7	1548.00	1230.00	1668.00
251	301.20	8	1470.00	1176.00	1662.00
253	303.60	6	1248.00	1248.00	1620.00
254	304.80	6	1170.00	972.00	1278.00
255	306.00	6	1068.00	1068.00	1182.00
256	307.20	5	1392.00	1206.00	1086.00
258	309.60	10	1746.00	1332.00	1914.00
260	312.00	6	720.00	720.00	1122.00
263	315.60	7	1194.00	1194.00	1656.00
264	316.80	5	1036.00	1036.00	966.00
265	318.00	5	1152.00	930.00	924.00
268	321.60	6	1188.00	1188.00	1146.00
269	322.80	7	1182.00	1182.00	1254.00
271	325.20	6	1164.00	1164.00	1224.00
272	326.40	6	1254.00	1044.00	1362.00
273	327.60	6	996.00	996.00	1086.00
274	328.80	6	1128.00	1128.00	1530.00
275	330.00	6	1206.00	960.00	1314.00
276	331.20	9	1404.00	1098.00	1596.00
277	332.40	7	1500.00	1302.00	1566.00

TABLE III - 1 (d). BUR SCHEDULES

SLICE NUMBER	AZIMUTH	NUMBER OF TARGETS	SYNCHRO CALL (NOTE 1)	SYNCHRO CALL (NOTE 2)	SYNCHRO CALL (NOTE 3)
6	7.20	7	1248.00	1002.00	1440.00
8	9.60	6	936.00	936.00	1284.00
10	12.00	7	1092.00	894.00	1212.00
11	13.20	6	1170.00	972.00	1212.00
12	14.40	7	1284.00	1002.00	1404.00
16	19.20	7	1260.00	966.00	1428.00
21	25.20	5	966.00	966.00	1066.00
25	30.00	7	1224.00	1038.00	1344.00
30	36.00	5	882.00	882.00	960.00
38	45.60	5	1098.00	1098.00	1110.00
39	46.80	5	1284.00	1062.00	942.00
40	48.00	6	948.00	948.00	1374.00
42	50.40	5	666.00	666.00	996.00
43	51.60	6	1236.00	1236.00	1374.00
45	54.00	6	1446.00	1260.00	1020.00
47	56.40	6	1008.00	1008.00	1098.00
270	324.00	5	1038.00	1038.00	1050.00
275	330.00	5	918.00	918.00	930.00
278	333.60	6	1230.00	996.00	1338.00

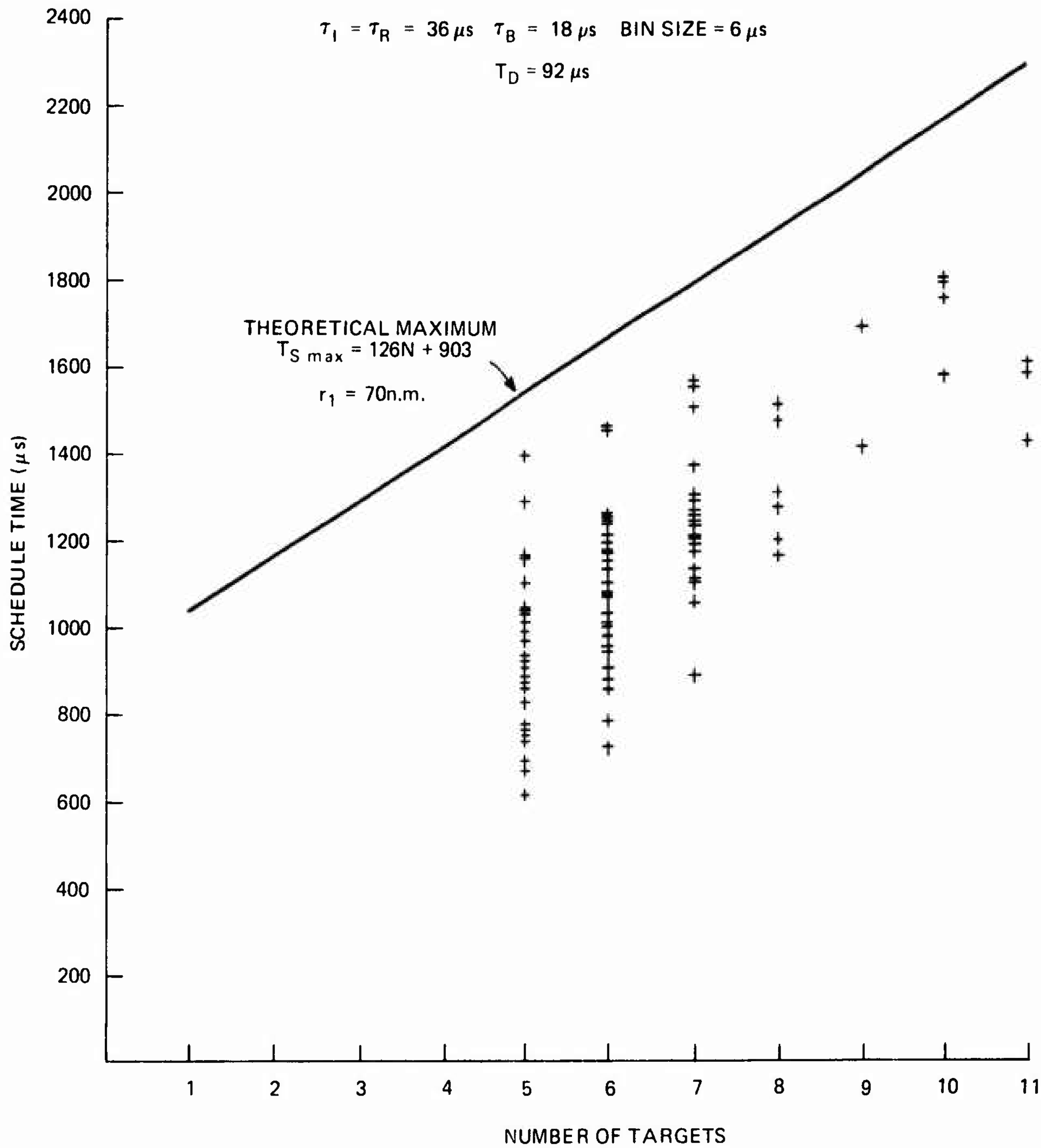


Figure III-2(a) SYNCHRO CALL SCHEDULE TIME REPLIES SCHEDULED
SUB - EPOCH TIMING
LAX 1995 4 SITE MODEL

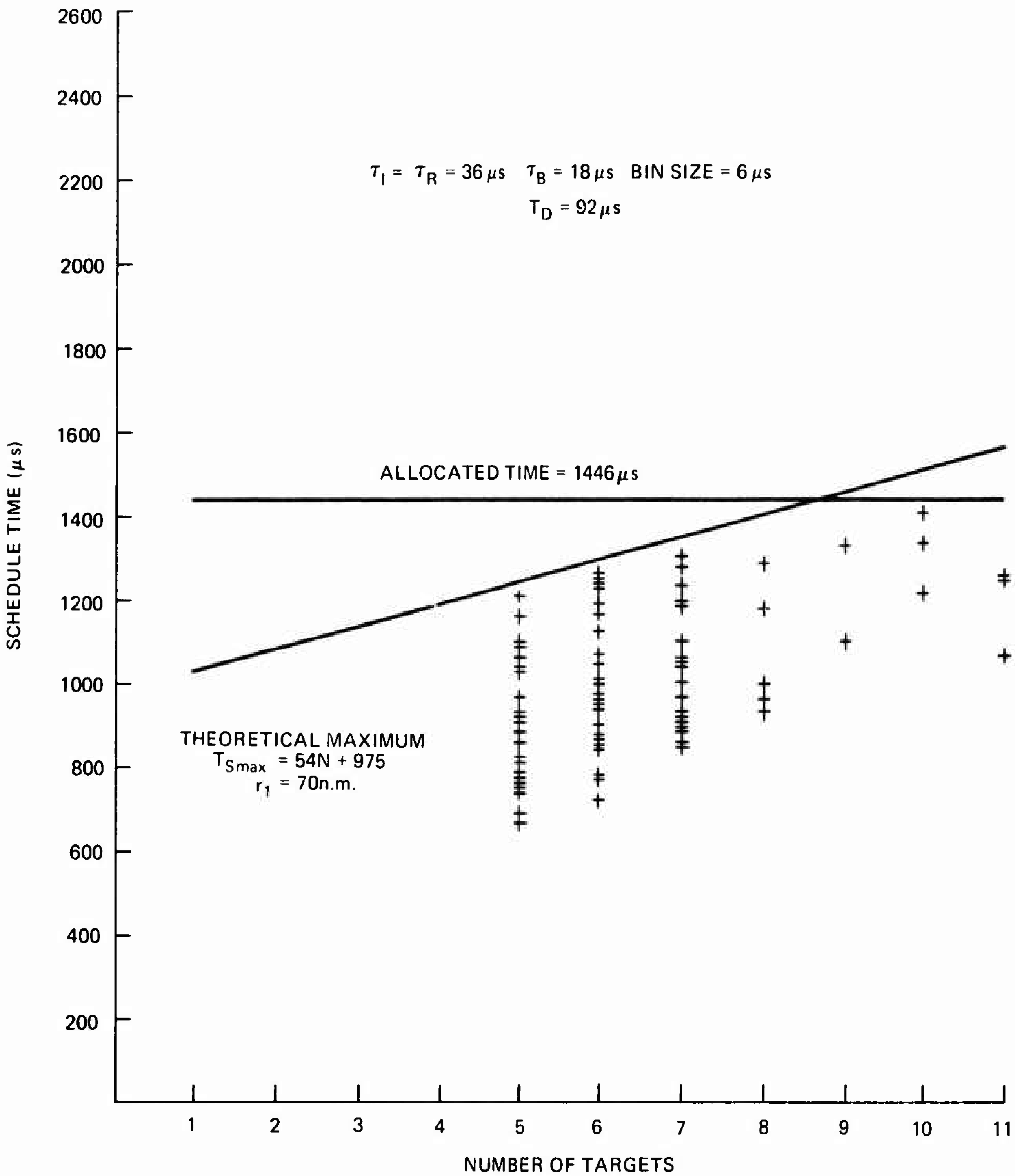


Figure III-2(b). SYNCHRO CALL SCHEDULE TIME
NO REPLY SCHEDULING
SUB EPOCH TIMING
LAX 1995 MODEL - 4 SITES

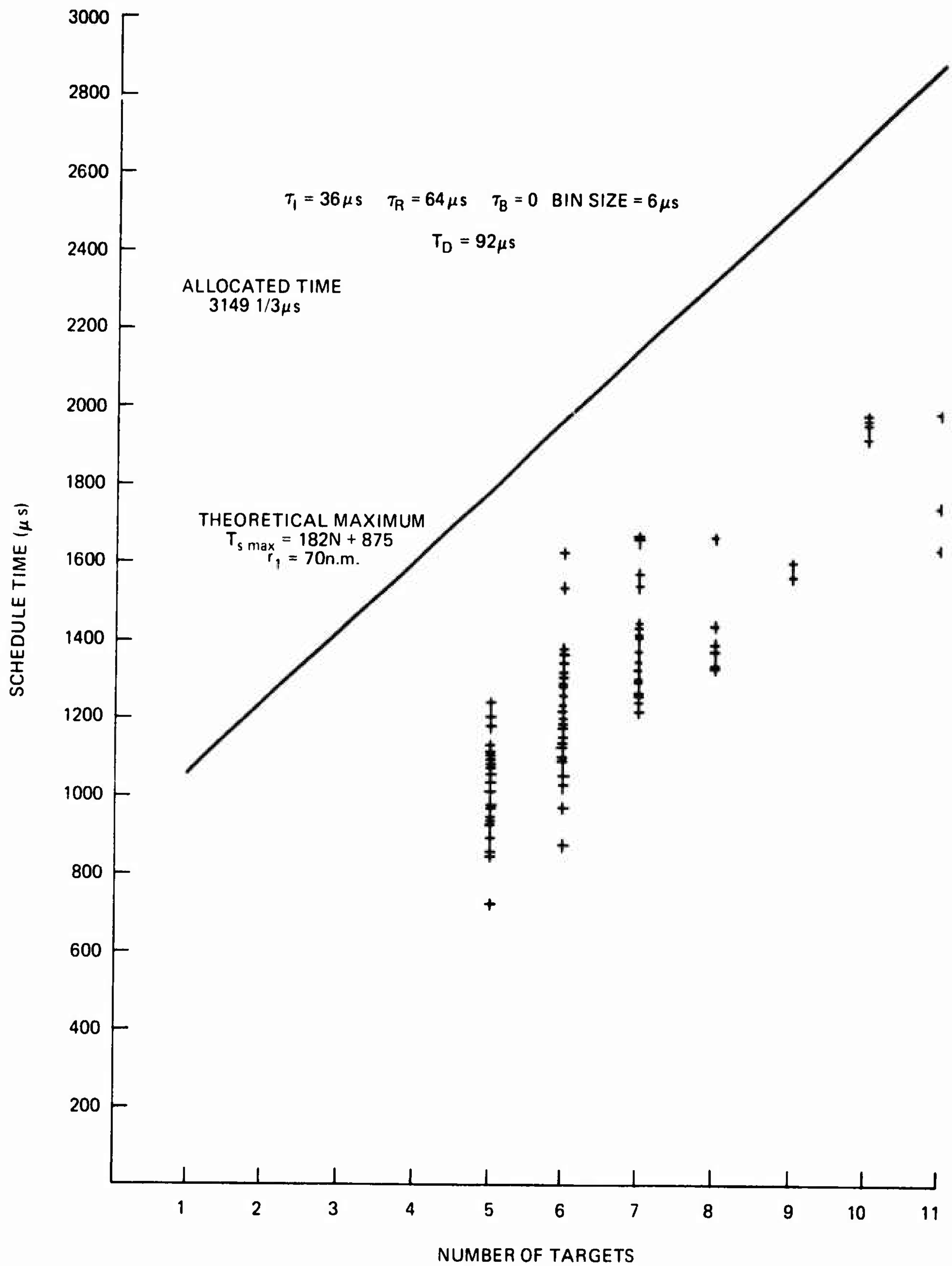


Figure III-2(c)

PACKED CALL SCHEDULE TIME
LAX 1995 - 4 SITE MODEL

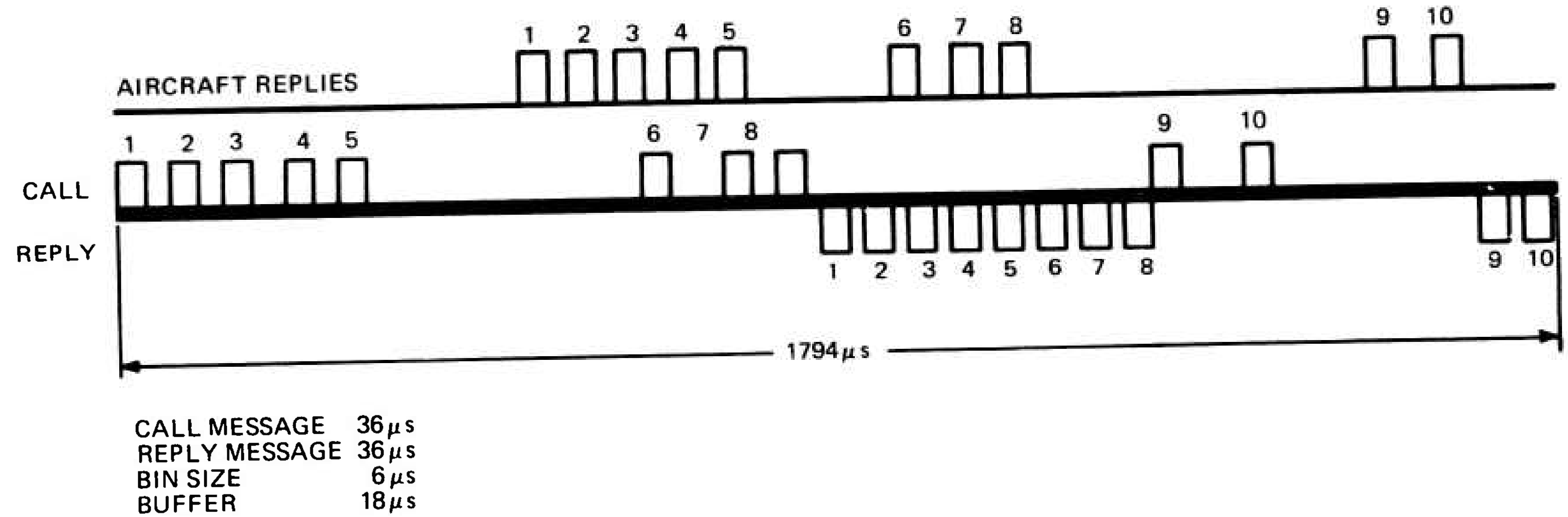
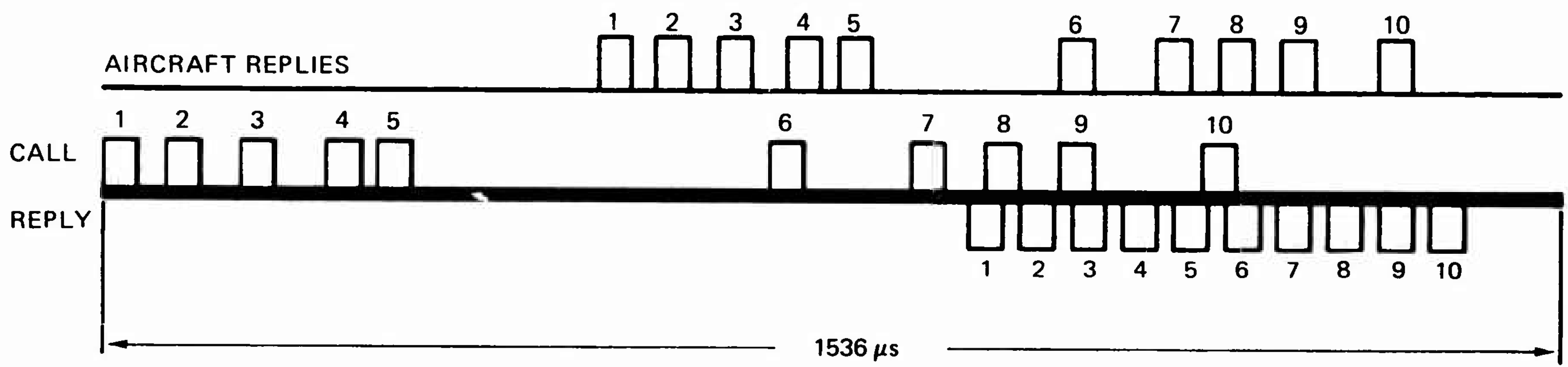


Figure III-3(a). Synchro Call Schedule (Replies Scheduled)
Lax Slice No.75,10 Targets



CALL MESSAGE 36 μs
REPLY MESSAGE 36 μs
BIN SIZE 6 μs
BUFFER 18 μs

SCHEDULE TIME 1440 μs

Figure III-3(b). Synchro Call Schedule (Replies Not Scheduled)

March Slice No.227,10 Targets

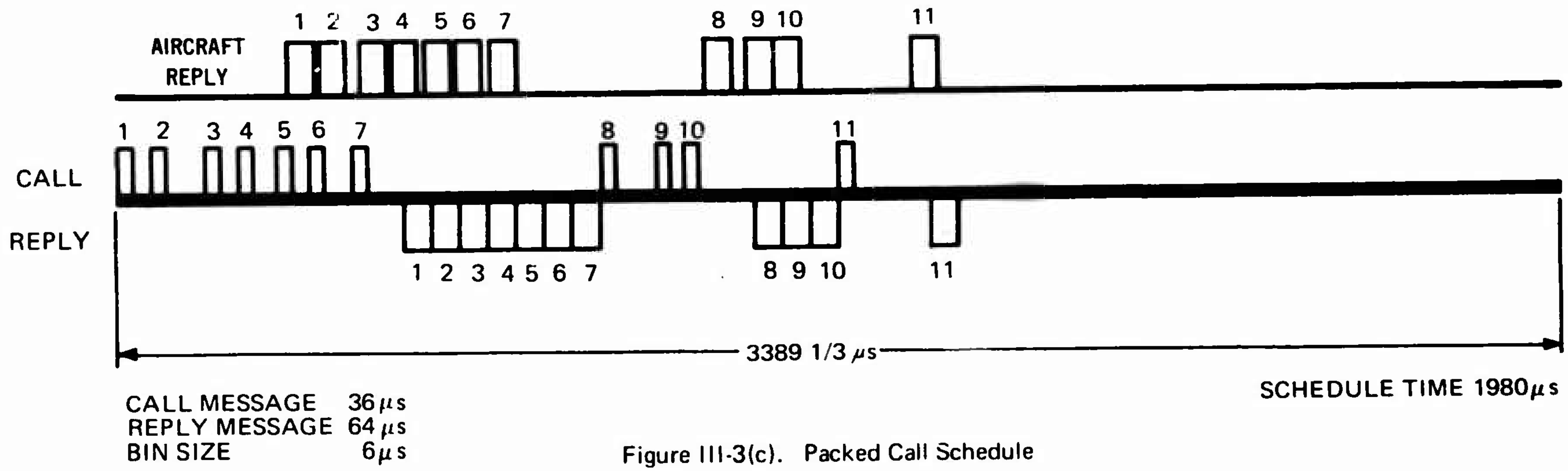


Figure III-3(c). Packed Call Schedule
March Slice No.281,11 Targets

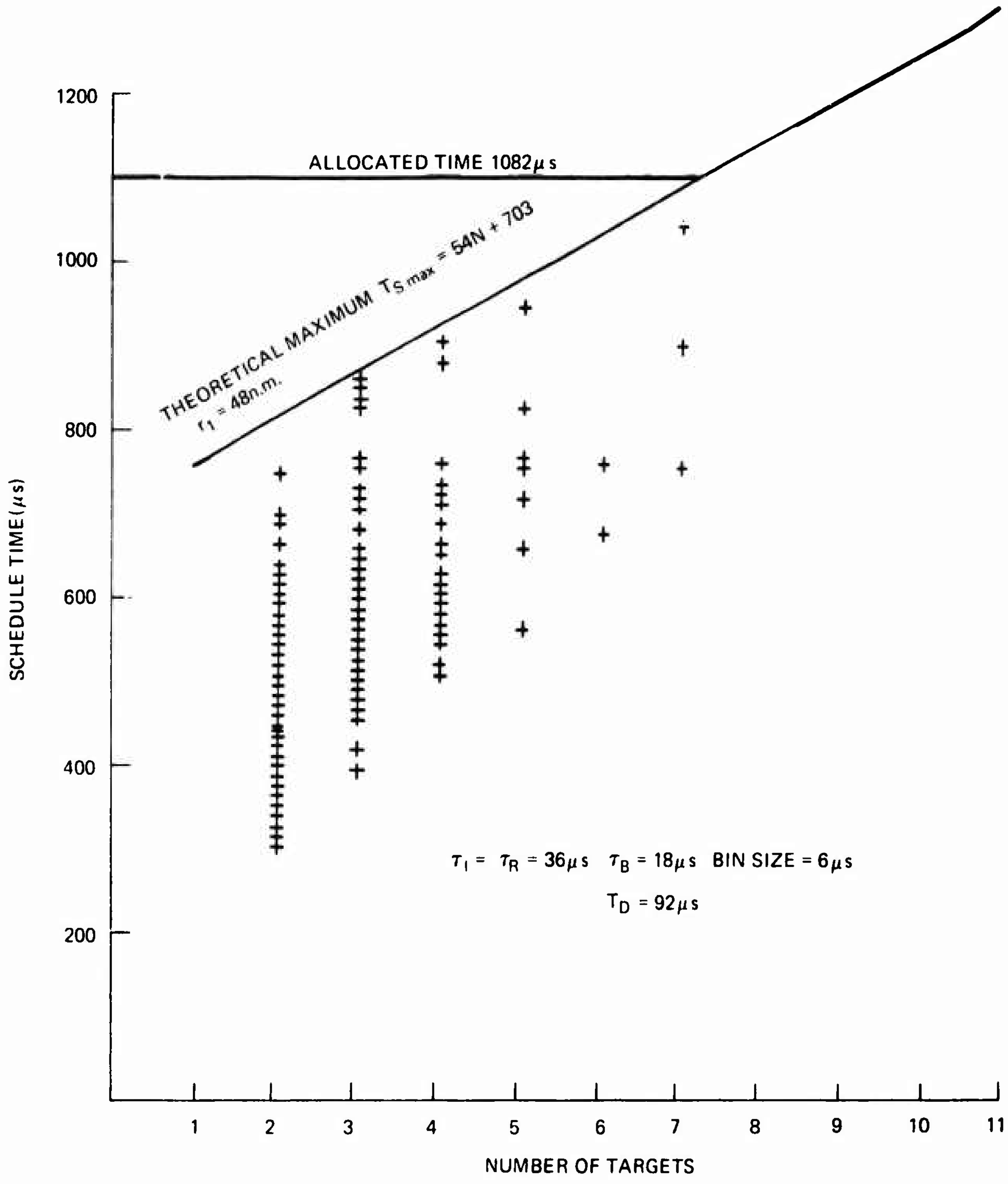


Figure III-4(a) SYNCHRO CALL SCHEDULE TIME
NO REPLY SCHEDULING
SUB EPOCH TIMING
LAX 1995 MODEL - 8 SITES

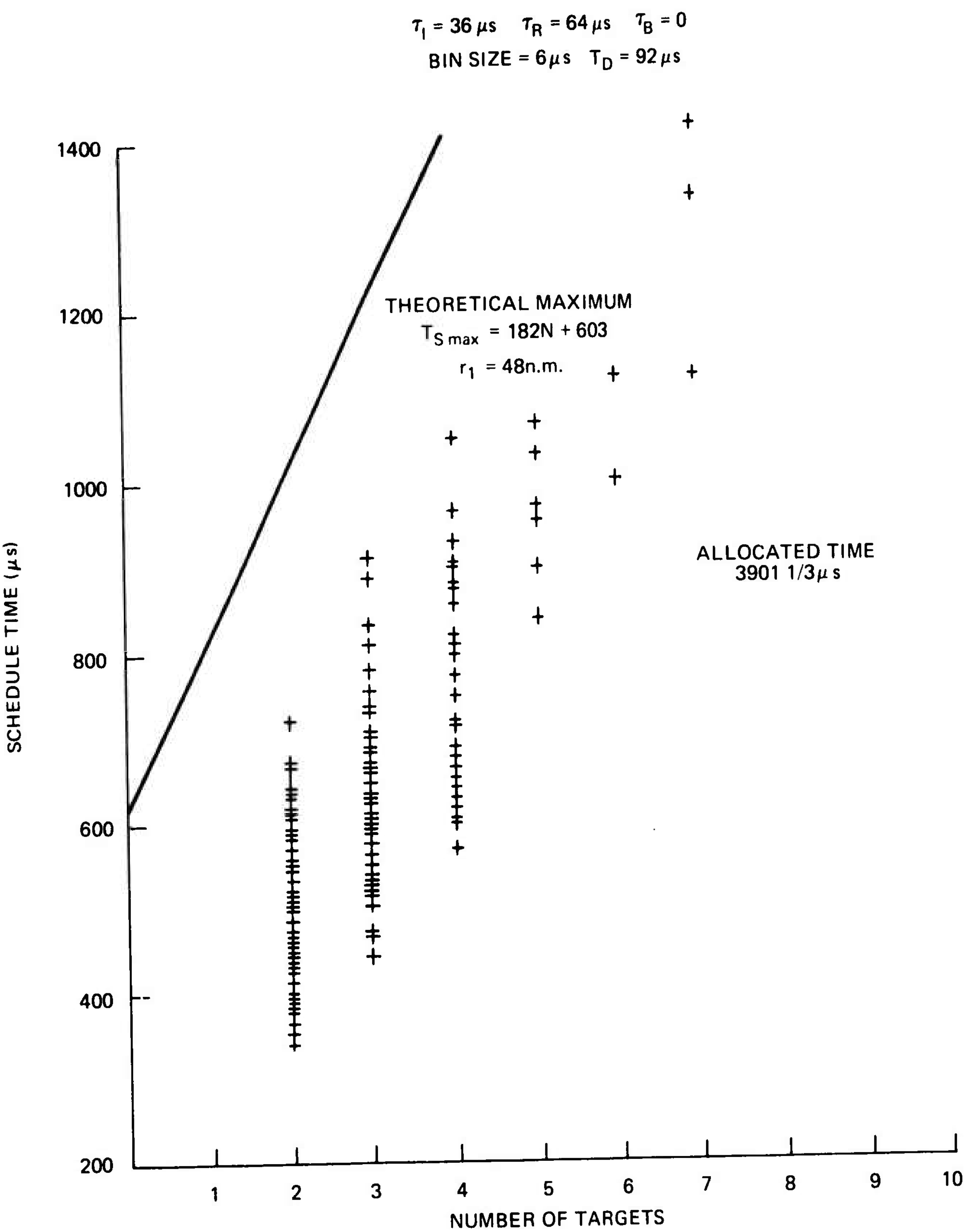


Figure III-4(b). PACKED CALL SCHEDULE TIME
LAX 1995 - 8 SITE MODEL

IV. FAILURE MODE - SITE OUTAGE

The case of a DABS site outage in the LA Basin was examined with respect to the ability of the remaining sites to handle the 1995 traffic. Specifically, the four site case (Chapter II) was simulated since the eight site case is obviously better able to handle a single site outage. The normal four site operation in effect before the assumed site failure is summarized by Figure II-1 (four sites, site boundaries, and traffic model) and Figure II-3 (multi-site interrogation schedule).

There were two advantageous factors to consider at the outset of this analysis. The first is that the packed call interval had been made extra long in the original four site normal schedule. (3149 1/3 μs was allotted where only 2754 μs was required theoretically, based on $N=11$ and $r_1=60$ n.m. 1980 μs was the maximum ever required in the LA Basin Model computer analysis, as seen in Table III-1). The second factor is that when one site fails, its entire synchro call interval (1446 μs) becomes available for use by the other three sites as necessary to augment individual synchro call intervals or the common packed call interval. Note also the form of the equations for the maximum scheduling times. (Equations from Appendix D with parameters from Appendix A.) The packed call maximum scheduling time is given by

$$T_{s_{max}} = 182\ N_{max} + 12.36\ r_1 + 10 \qquad (1)$$

where N_{max} is the number of aircraft in the site's densest slice, r_1 is the maximum range to a target within the site boundary, and time is in μs. The similar equation for the synchro call (no reply scheduling) is

$$T_{s_{max}} = 54\ N_{max} + 12.36\ r_1 + 110 \qquad (2)$$

As a hypothetical example, assume the entire LA Basin is handled by two sites. Assume one fails and the other carries the load. (The entire synchro call interval of the failed site will be available to the remaining site.) The key factor is that although the traffic of the remaining site doubles, N_{max} and r_1 in the above two equations will not double. In fact, neither will increase by even 50% for reasonable geometries and traffic distribution. The effect on r_1 can be seen on a boundary map. The effect of N_{max} is explained qualitatively by the fact that the extra traffic is picked up in slices which previously had few targets.

The exact quantitative schedules have been computed for the four cases of each site separately failing in the four site model. There are 300 slices per site, three sites per case, and four cases. All of the resulting 3600 slices were scheduled for both packed and synchro calls on the CDC 6400 time sharing system. Only the most time-consuming of the 7200 schedules have been included in the various tables explained in this chapter.

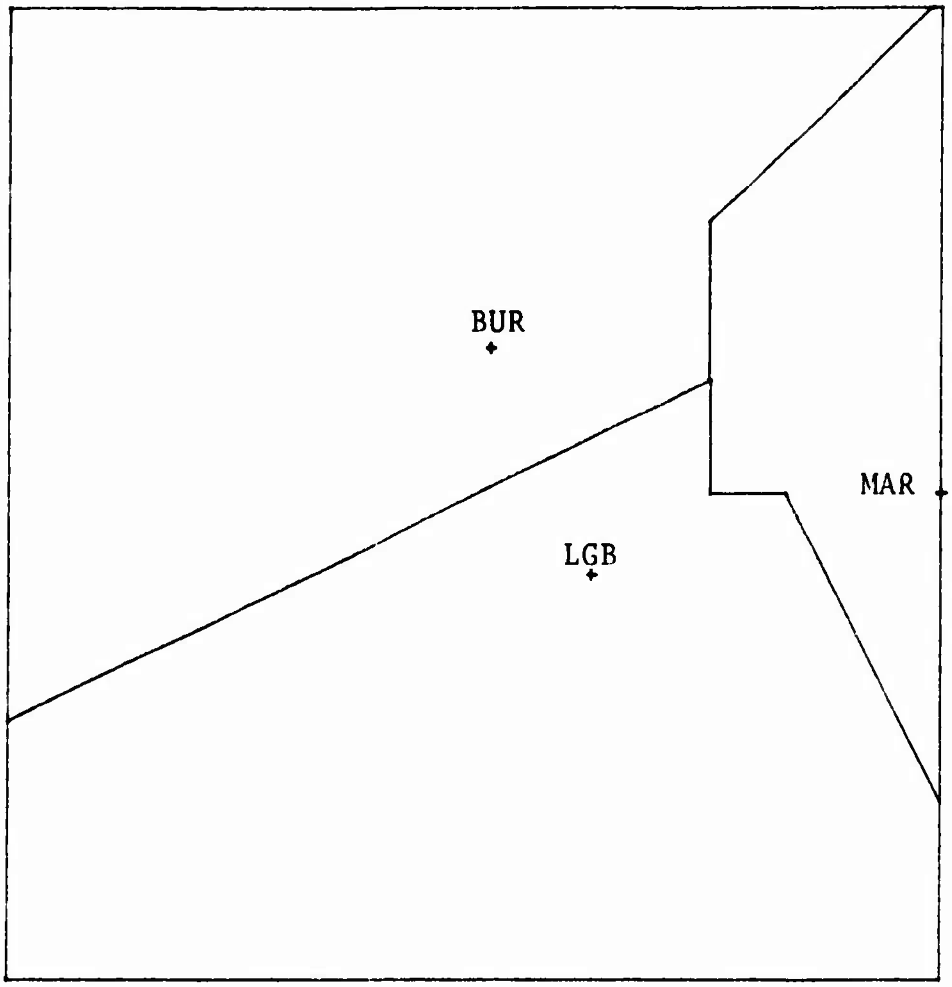
Note that in all four cases the proposed boundaries shown for the three remaining sites have not been optimized. They were chosen based on engineering judgment following an inspection of appropriate traffic densities and slice densities. However, in all cases feasible multi-site schedules were computed using the proposed boundaries.

IV. 1 LAX DABS SITE FAILURE

The proposed boundaries for the three remaining sites in the case of a failure at LAX are shown in Figure IV-1. Comparing this to the normal four site boundaries (Figure II-1) shows that the LAX targets are being handled by BUR and LGB slices which previously had few targets of their own. Therefore, we would not expect large increases in schedule times for BUR and LGB. MAR boundaries and schedule times are unchanged. Its synchro call interval remains at 1446 μs (see Figure II-3).

Results of the computer analysis for BUR and LGB with LAX out are shown in Table IV-1. BUR and LGB synchro call requirements are now 1551 μs and 1818 μs, respectively; MAR remains at 1446 μs. These three add to 4815 μs. This is 969 μs less than the 5784 μs allotted for the four synchro calls during the no-failure case (see Figure II-3). The extra 969 μs can be added to the no-failure packed call interval (3149 1/3 μs), giving a packed call interval of 4118 1/3 μs. Note, however, that even without the 969 μs addition, the no-failure 3149 1/3 μs packed call interval was sufficient to handle the new packed call requirements of BUR and LGB (see Table IV-1).

The LAX-failure multi-site interrogation schedule is summarized in Table IV-2.



Square centered at LAX with 120 n.m. sides

Site	#Aircraft	Max aircraft in one slice	Overlooks
BUR	705	9	BUR over MAR
LGB	444	11	MAR over LGB
MAR	456	11	LGB over BUR
TOTAL	1605		

FIGURE IV - 1. Reconfigured Boundaries for Failure of LAX DABS Site

TABLE IV-1

SCHEDULE TIMES FOR IMPACTED SITES (ALL FOUR FAILURE CASES)

Failure	Site	Aircraft Handled	N_{max}	r_1	SYNCHRO CALL T_{smax} Theory	SYNCHRO CALL T_{smax} Observed	PACKED CALL T_{smax} Theory	PACKED CALL T_{smax} Observed
LAX Out	BUR	705	9	77.2	1,551	1,350	2,603	1,602
LAX Out Note 1	LGB	444	11	90.1	1,818	1,062	3,126	1,632
LGB Out	LAX	634	10	67.1	1,480	1,332	2,660	1,914
LGB Out Note 2	MAR	585	11	67.1	1,534	1,440	2,842	1,980
BUR Out Note 3	LAX	823	16	84.9	2,024	1,704	3,972	2,628
MAR Out Note 4	BUR	808	16	71.6	1,859	1,764	3,807	2,658

Note 1 With LAX out, there is no change in MAR boundaries, traffic, or schedule times.

Note 2 With LGB out, there is no change in BUR boundaries, traffic, or schedule times.

Note 3 With BUR out, there is no change in LGB or MAR boundaries, traffic, or schedule times.

Note 4 With MAR out, there is no change in LAX boundaries, traffic, or schedule times. LGB has a small change in boundaries and traffic which does not cause its schedule times to exceed that normally budgeted for the four site case.

TABLE IV-2

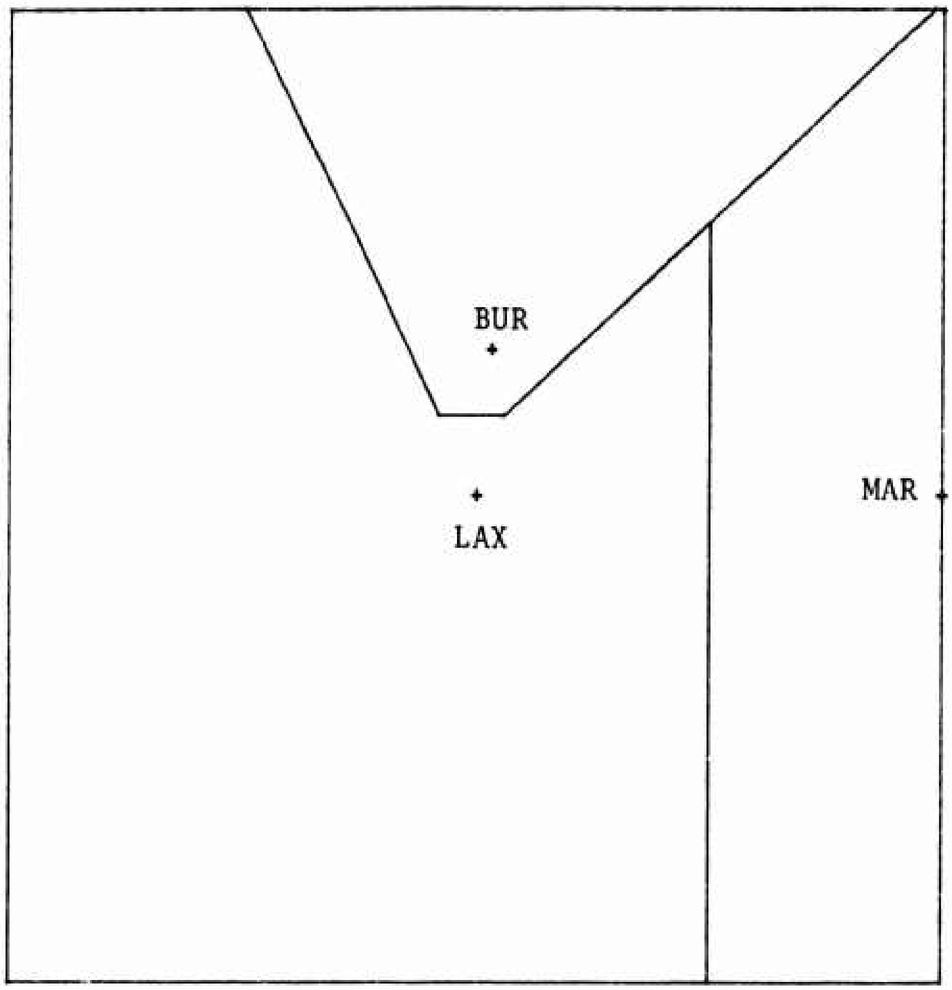
MULTI-SITE INTERROGATION SCHEDULE - LAX FAILURE

Packed Call	4,118 1/3 µs
ATCRBS	2,200
Synchro Call-BUR	1,551
Synchro Call-LGB	1,818
Synchro Call-MAR	1,446
ATCRBS	2,200
TOTAL	13,333 1/3 µs

IV.2 LGB DABS SITE FAILURE

The reconfigured boundaries with LGB out are shown in Figure IV-2. LAX and MAR pick up all of the LGB traffic in their sectors which were previously sparsely populated. Thus, we do not expect significant increases in schedule time for those two sites. This is borne out by computer results in Table IV-1. LAX and MAR synchro call schedule times are 1480 and 1534 µs, respectively. BUR boundaries and traffic are unchanged, thus its synchro call remains at 1446 µs. The sum of the three synchro calls is 4460 µs, which is 1324 µs less than the no-failure value of 5784 µs. This 1324 µs can be added to the no-failure packed call of 3149 1/3 µs to give a 4473 1/3 µs packed call. Note that even without the additional 1324 µs, the no-failure packed call interval was long enough to handle LGB-out traffic of the three remaining sites (see Table IV-1).

The LGB-out multi-site interrogation schedule is summarized in Table IV-3.



Square centered at LAX with 120 n.m. sides

Site	#Aircraft	Max aircraft in one slice	Overlooks
LAX	634	10	BUR over MAR
BUR	386	7	MAR over LAX
MAR	585	11	LAX over BUR

FIGURE IV - 2. Reconfigured Boundaries for Failure of LGB DABS Site

TABLE IV-3

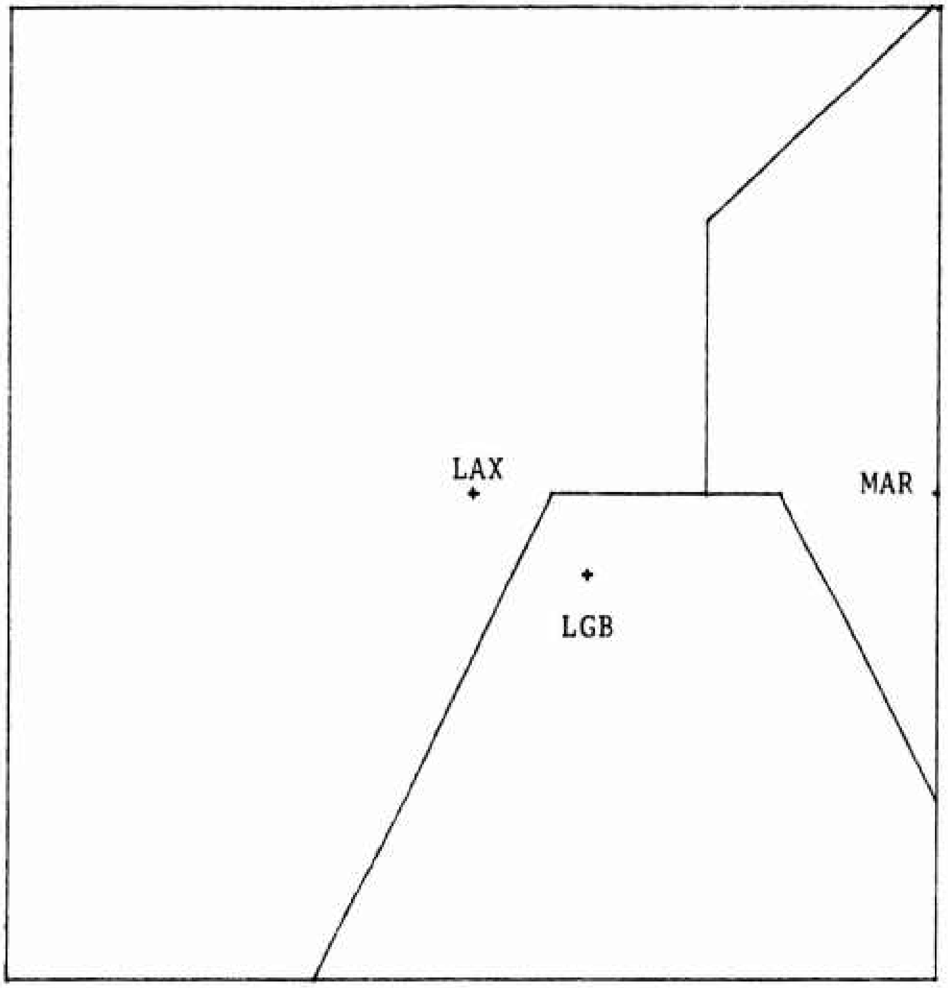
MULTI-SITE INTERROGATION SCHEDULE - LGB FAILURE

Packed Call	4,473 1/3 µs
ATCRBS	2,200
Synchro Call-LAX	1,480
Synchro Call-BUR	1,446
Synchro Call-MAR	1,534
ATCRBS	2,200
TOTAL	13,333 1/3 µs

IV.3 BUR DABS SITE FAILURE

The situation with BUR out is somewhat different from the two previous cases. Here, there was no way to distribute the BUR traffic among low density slices of other sites. Thus, it was inevitable that N_{max} increase above 11 targets per slice, which had been its value in the no-failure case, with LAX out, and with LGB out. The heavy distribution of MAR traffic to the northwest of MAR left that site with little capability to pick up any BUR traffic. Thus, the entire BUR load was given to LAX, which was fairly lightly loaded in the direction of BUR. This left MAR and LGB unchanged, as shown in Figure IV-3.

N_{max} for LAX rose to 16 targets per slice, and r_1 increased to 84.9 n.m. This required a synchro call interval of 2024 µs and a packed call of 3972 µs. Note that this packed call requirement is well above the pre-failure packed call interval of 3149 1/3 µs (see Figure II-3). Fortunately, the decrease in synchro call requirements of three sites compared to four sites left a sufficient margin to add to the packed call and meet that requirement. This is shown in Table IV-4.



Square centered at LAX with 120 n.m. sides

Site	#Aircraft	Max aircraft in one slice	Overlooks
LAX	823	16	LAX over MAR
LGB	326	11	MAR over LGB
MAR	456	11	LGB over LAX
TOTAL	1605		

FIGURE IV - 3. Reconfigured Boundaries for Failure of BUR DABS Site

TABLE IV-4

MULTI-SITE INTERROGATION SCHEDULE - BUR OUT

Packed Call	4,017 1/3 μs
ATCRBS	2,200
Synchro Call-LAX	2,024
Synchro Call-LGB	1,446
Synchro Call-MAR	1,446
ATCRBS	2,200
TOTAL	13,333 1/3 μs

IV.4 MAR DABS SITE FAILURE

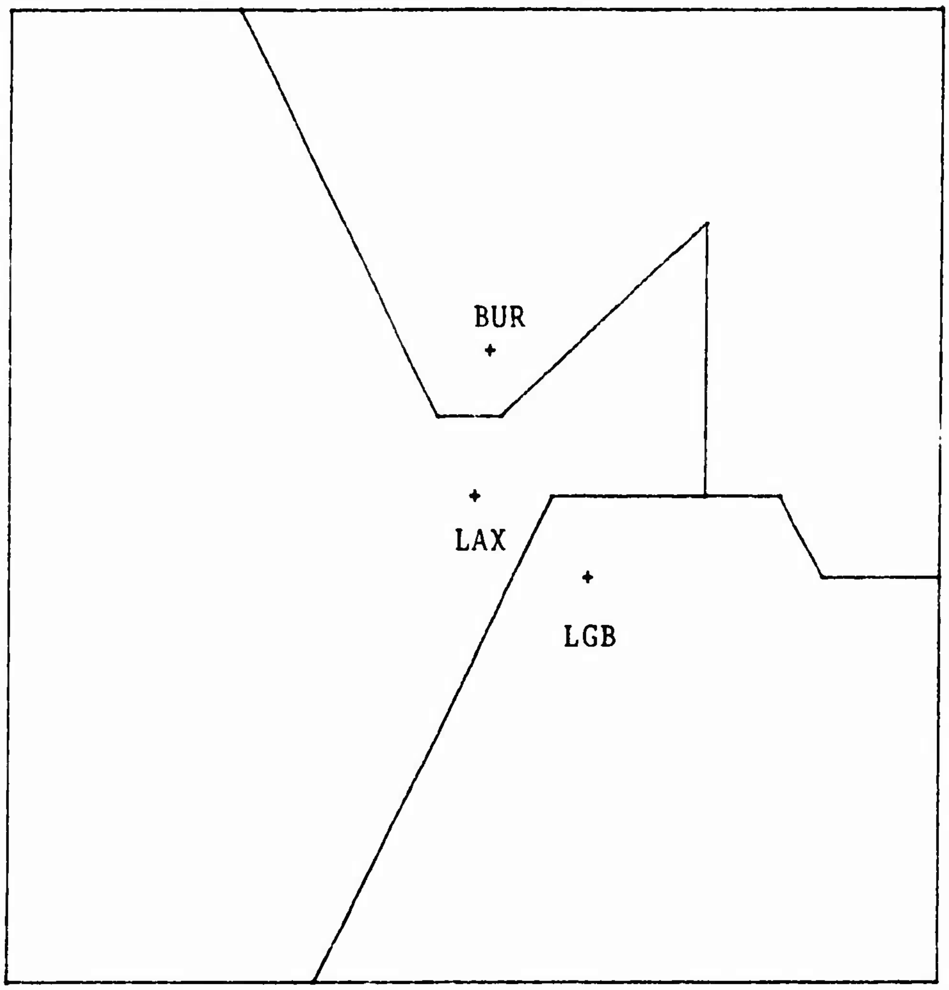
The proposed boundaries with MAR out are shown in Figure IV-4. BUR has been given most of the MAR traffic since LAX and LGB already had high slice densities in the direction of MAR, whereas BUR did not.

Table IV-1 shows the BUR synchro and packed call requirements to be 1859 and 3807 μs, respectively. Again the packed call requirement exceeds the no-failure packed call interval. However, the difference can be more than made up by the synchro calls. The resulting schedule is shown in Table IV-5.

TABLE IV-5

MULTI-SITE INTERROGATION SCHEDULE - MAR OUT

Packed Call	4,182 1/3 μs
ATCRBS	2,200
Synchro Call-LAX	1,446
Synchro Call-BUR	1,859
Synchro Call-LGB	1,446
ATCRBS	2,200
TOTAL	13,333 1/3 μs



Square centered at LAX with 120 n.m. sides

Site	#Aircraft	Max aircraft in one slice	Overlooks
BUR	808	16	LAX over BUR
LAX	437	10	BUR over LGB
LGB	360	11	LGB over LAX
TOTAL	1605		

FIGURE IV - 4. Reconfigured Boundaries for Failure of MAR DABS Site

CHAPTER V. CONCLUSIONS

The fundamental result of this work is that a partitioned, time-shared, sub-epoch interrogation scheduling technique is completely adequate to handle the projected capacity of the Los Angeles Basin in 1995 (over 1600 aircraft) and is capable of providing garble-free Synchro DABS service (within the main beam) in a multi-site, DABS/ATCRBS environment. Aircraft reply message length is normally 64 μs with additional time available for extended length messages and target reinterrogations during the packed call. Synchro DABS aircraft reply message length is 36 μs. In order to achieve these results, the ATCRBS PRF was reduced to 150 (7 hits per scan), but high uplink reliability was introduced by using time synchronization of ATCRBS sites with the firing time of each site calculated as a function of antenna azimuth. This eliminates transponder suppression due to asynchronous multiple site interrogations.

A specific scheduling algorithm has also been developed and verified both by simulation and analysis and requires only one piece of operational software for implementation. These techniques have been applied to verify both a 4 DABS site/8 ATCRBS site model and an 8 DABS/8 ATCRBS site model of the 1995 LA Basin. Either model can be reconfigured to service the traffic in the event of a failure of any one DABS site.

It should be further pointed out that the results of other OSEM analyses and simulations performed indicate that neither epoch timing for Synchro DABS nor sub-epoch timing with Synchro DABS replies scheduled for ground reception can accommodate the 1995 LA Basin model, unless some combination of antenna azimuth synchronization, beam agility, and site offloading are used.

APPENDIX A. SCHEDULING ALGORITHM DESCRIPTION, FLOW CHART, AND FORTRAN LISTING

The description and detailed flow charts of the single site interrogation scheduling algorithm discussed in Chapter III are presented in this Appendix. A FORTRAN listing of the computer program is also included.

Before the scheduling program is entered, all targets which must be called by the DABS are azimuth-sorted into slices (nominally there are 300 slices, each 1.2 degrees wide). Each slice is handled separately by the scheduling algorithm. The ranges of all aircraft in the slice to be scheduled are input in decreasing range order. The inputs to the program which remain constant for all slices follow. (Input statements are included in the FORTRAN listing but not in the flow chart.)

TAUI (τ_I) Interrogation message length, μs.

TAUR (τ_R) Reply message length, μs.

BINSIZ Bin size, i.e., bin length, μs. During synchro calls, all aircraft must begin their transmissions at the exact beginning of a bin (sub-epoch). The aircraft Synchro-DABS transmission contains a six bit word identifying the bin or sub-epoch number during which that transmission began.

LINTVL Length of interval to be scheduled, μs. (This should always exceed the amount of time required to schedule all aircraft in any one slice; as long as this is true, LINTVL has no effect on the schedule.)

TD (T_D) Transponder delay, μs. DABS airborne transponders are designed to have a built-in fixed delay, TDTOTAL, measured from the time the beginning of the interrogation arrives until the time the beginning of the reply is transmitted. TD as used in this program is defined as:

$$TD = TDTOTAL - TAUI$$

NOTE: In the flow chart as in the FORTRAN listing, the standard FORTRAN variable naming convention is followed: all integer variables begin with I, J, K, L, M, N; all real variables begin with any other letter (e.g., RBX (integer) is called KRBX in this flow chart and program).

In other words, TD is the time from the end of the interrogation to the start of the reply.

TAUB (τ_B) Buffer time, µs. During synchro calls (not packed calls) air-to-air CAS garble constraints require that any two successive replies arrive at the DABS antenna separated by an interval of at least TAUB µs. This is to insure that when the same successive replies arrive at any aircraft, the two replies at least do not overlap. The reason this interval of silence at the antenna, TAUB, can be diluted (and therefore must be made large enough so as not to ever be diluted to zero) is due to the possible difference in the three dimensional positions of two aircraft both at the same DABS range, R. For example, consider two aircraft both in the same 1.2 degree slice and both at 60 n.m. range from the antenna. If one aircraft is at the far "left" side of the slice and low, and the other aircraft is at 42,000 feet at the far "right" side (i.e., 1.2 degree azimuth difference between the two), then the two aircraft are six n.m. apart.

TAUB is required to keep the reply of the first aircraft ahead of (and not overlapping) the reply of the second, when measured at the location of a third aircraft which is very near the second (but in the next slice). In this program a fixed value of TAUB was used, chosen large enough for most cases. At the expense of increased computation, the exact value of TAUB could be calculated and used between every two successive aircraft. This would involve computing the distance between the aircraft using the Pythagorean Theorem in three dimensions (azimuth, altitude, and slant range).

Numerical values for all parameters defined above are given in Table A-1.

OVERALL PROGRAM STRUCTURE

The central portion of the FORTRAN program is the Schedule Generator. For each slice, the Schedule Generator is used three times: for the

TABLE A-1 SYSTEM PARAMETERS

Interrogation Message Length	τ_I	36 μs
Response Message Length	τ_R	
Packed Call		64 μs
Synchro Call		36 μs
Synchro Call Buffer Time*	τ_B	18 μs
Transponder Delay* (measured after end of interrogation)	T_D	92 μs
Sub-Epoch Bin Length	BINSIZ	6 μs
Antenna Rotation Rate		90 deg/sec
DABS Slice Width		1.2 degrees
Maximum Range	r_l	60 n. m.

* A more precise definition is given earlier in this Appendix.

synchro call with reply scheduling,* the synchro call without reply scheduling, and the packed call. (It then asks for the ranges of the aircraft in the next slice). If the Schedule Generator is entered with the reply scheduling flag, IREPSC, set equal to 1, it schedules replies to meet all constraints upon reception at the DABS antenna (synchro call with reply scheduling and packed call). If IREPSC = 0, replies are ignored at the DABS antenna (synchro call without reply scheduling). If the Schedule Generator receives a positive value of TAUB, it schedules either type of synchro call. If a zero value of TAUB is input, it schedules a packed call. This structure is shown in the flow chart of Figure A-1.

Thus, in Figure A-1, it is seen that the program proceeds in the following manner:

(1) Parameters are input (TAUI, TAUR, etc.).

(2) Aircraft ranges for the slice to be scheduled are input.

(3) The synchro call with reply scheduling is scheduled. Results are printed.

(4) The synchro call without reply scheduling is scheduled. Results are printed.

(5) The packed call is scheduled. Results are printed.

(6) Go to (2) above and start the next slice.

In Figure A-1 the Schedule Generator, which makes up the bulk of the computer program, is represented by a single block. The Schedule Generator is described in a one-page overview flow chart (Figure A-2) and then in a detailed flow chart (Figure A-3). Description of the program strategy and definition of variables are contained in the flow charts.

A FORTRAN listing of the program is included. This program was run on the CDC 6400 Kronos Time Sharing System.

At the end of the Appendix there are several miscellaneous notes on the computer program, included for the benefit of later users.

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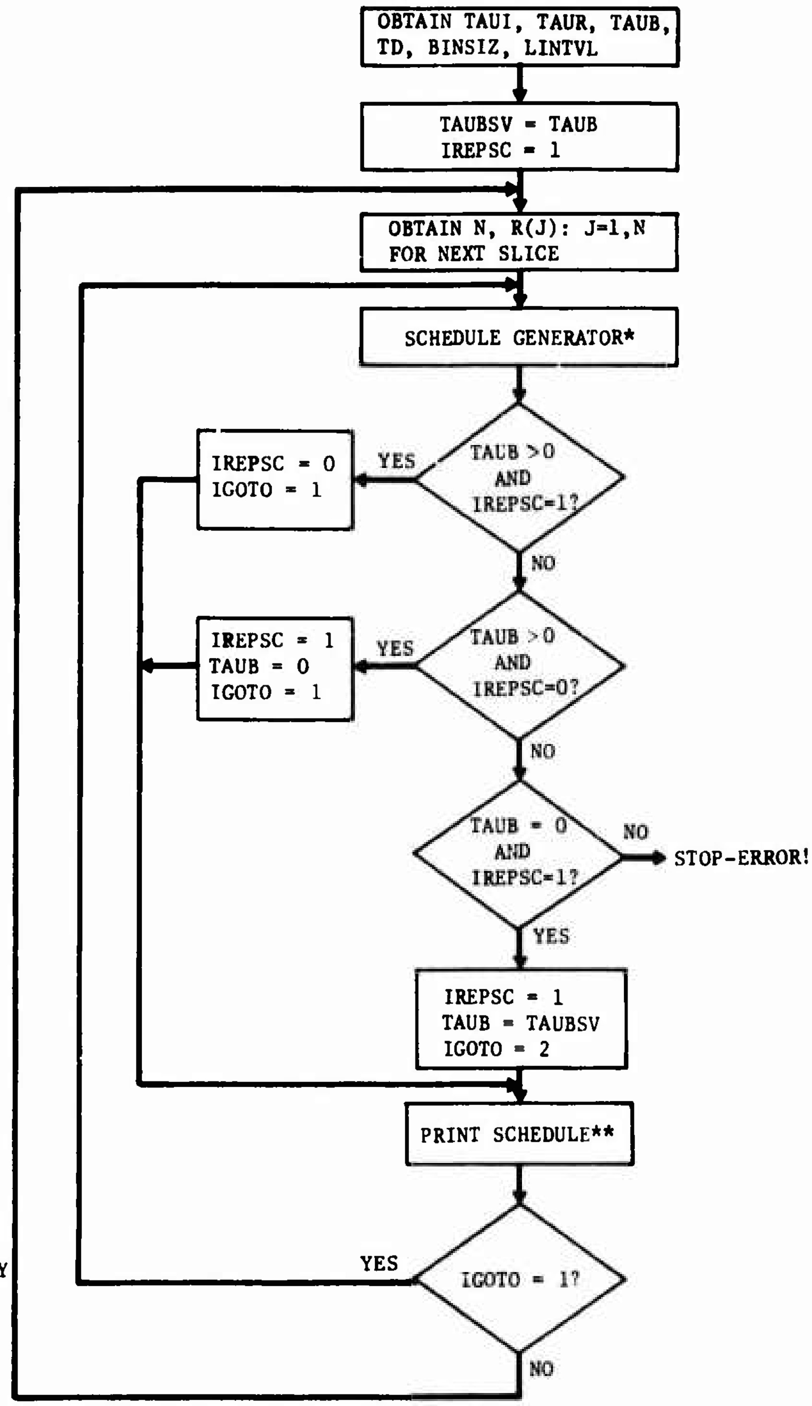
*As discussed in Chapter I, the synchro call with reply scheduling proved too time consuming; thus, the synchro call without reply scheduling is recommended for high density areas. The FORTRAN program, however, schedules both types of calls for comparison.



NOTES: * SCHEDULE GENERATOR DESCRIBED IN SEPARATE FLOW CHART.

** ONLY ONE OF THE THREE TYPES OF SCHEDULES IS PRINTED FOR EACH ENTRY INTO "PRINT SCHEDULE" BOX.

N = NUMBER OF AIRCRAFT IN SLICE.

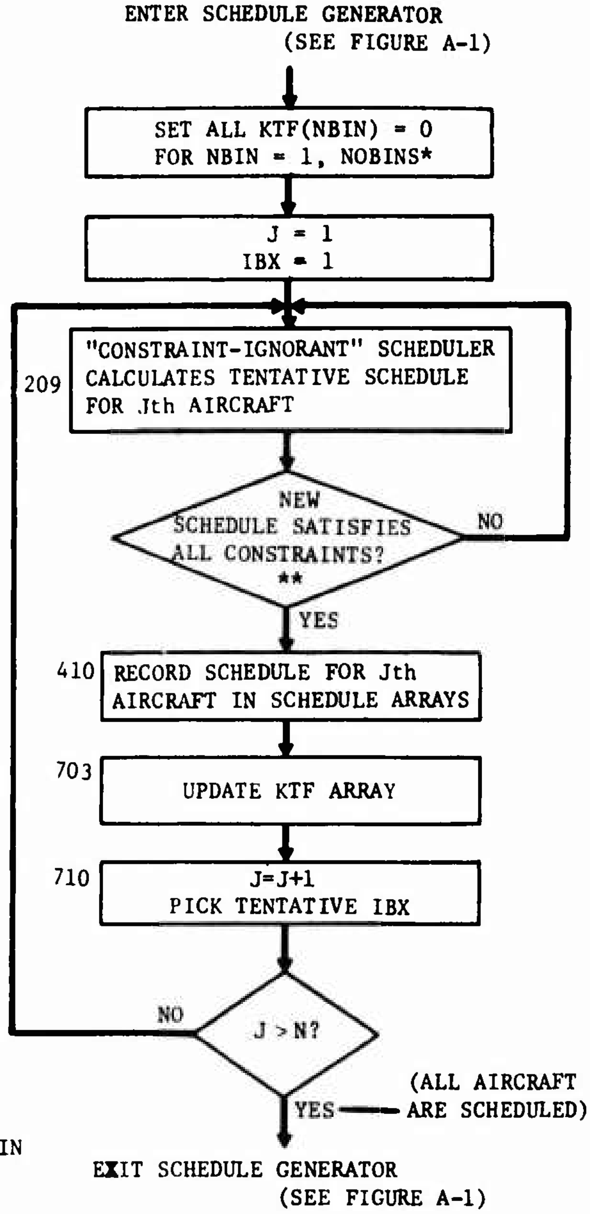
R(J) = RANGE OF Jth AIRCRAFT (AIRCRAFT HAVE ALREADY BEEN SORTED IN DESCENDING RANGE ORDER).

TAUBSV IS CREATED TO SAVE THE ORIGINAL VALUE OF TAUB DURING THE PACKED CALL, WHEN TAUB IS SET TO ZERO.

VARIABLES WHICH HAVE NAMES BEGINNING WITH I, J, K, L, M, N ARE INTEGERS. OTHERS ARE REAL VARIABLES.

FIGURE A-1

PROGRAM STRUCTURE FLOW CHART



NOTES: J = AIRCRAFT NUMBER

N = TOTAL NUMBER OF AIRCRAFT IN THE SLICE

IBX = INTERROGATION BIN INDEX

* KTF (NBIN) IS THE BIN POINTER FOR BIN NUMBER NBIN. FOR EXAMPLE, IF KTF(7)= 3, THE 7TH BIN IS OCCUPIED (WITH AN INTERROGATION OR RECEPTION) AND THE NEXT UNOCCUPIED BIN IS THE 7 + 3 = 10 TH BIN. NOBINS IS THE MAXIMUM NUMBER OF USEABLE BINS. NOBINS EQUALS THE NEXT INTEGER BELOW (LINTVL/BINSIZ) - I.E., TOTAL INTERVAL LENGTH DIVIDED BY BIN LENGTH.

** CONSTRAINTS ARE THAT NO CALLS OR RECEPTIONS CAN OVERLAP ANY OTHER CALLS OR RECEPTIONS AT THE DABS ANTENNA (EXCEPT RECEPTIONS CAN OVERLAP IF IREPSC = 0, I.E., SYNCHRO CALL WITHOUT REPLY SCHEDULING). ALSO THERE MUST BE A BUFFER OF AT LEAST TAUB BETWEEN RECEPTIONS AT THE ANTENNA FOR BOTH TYPES OF SYNCHRO CALLS. NOTE THAT THIS EVEN APPLIES TO SYNCHRO CALLS WITHOUT REPLY SCHEDULING. THIS MAY APPEAR CONFUSING AT FIRST: HOWEVER, THE SECTION ON TAUB (PAGE A-3) EXPLAINS THAT THIS BUFFER IS REQUIRED TO MEET THE AIR-TO-AIR GARBLE CONSTRAINT REQUIRED OF SYNCHRO CALLS. IT IS INDEPENDENT OF WHETHER OR NOT REPLIES ARE SCHEDULED FOR RECEPTION AT THE DABS ANTENNA.

FIGURE A-2
SCHEDULE GENERATOR OVERVIEW

ENTER SCHEDULE GENERATOR
(SEE FIGURE A-1)

SET ALL BIN POINTERS TO 0

```
1350 DO 1360 NBIN=1, NOBINS
KTF (NBIN) = 0
1360 CONTINUE
```

```
J = 1
IBX = 1
```

ENTRY 209

"CONSTRAINT-IGNORANT" SCHEDULER

```
209 TINTST = (IBX-1)*BINSIZ
T1WAY = R(J)*6.18
TREPST = TINTST+T1WAY+TAUI+TD
KEBX = INT(TREPST/BINSIZ)  + 2
TREPS = (KEBX-1)*BINSIZ
TINTS = TREPS-T1WAY-TAUI-TD
TINTE = TINTS + TAUI
NBINTE = INT (TINTE/BINSIZ) + 1
NI = NBINTE - IBX + 1
TRECS = TREPS + T1WAY
TRECE = TRECS + TAUR
KRBX = INT(TRECS/BINSIZ) + 1
NBRECE = INT(TRECE/BINSIZ) + 1
NR = NBRECE - KRBX + 1
```

CONTINUE ON PAGE B

FIGURE A-3
SCHEDULE GENERATOR DETAILED FLOW CHART

(PAGE A)

NOTES ON FIGURE A-3 (PAGE A)

Integer variables start with I,J,K,L,M,N; otherwise real.

- KTF (NBIN) = bin pointer for bin number NBIN (see Figure A-2).
- IBX = Interrogation Bin indeX - i.e., the number of the bin in which the DABS interrogation of the aircraft begins.
- TINTST = Time INTerrogation Starts - Temporary Value
- TINTS = Time INTerrogation Starts
- T1WAY = One way propagation time = Range x 6.18 usec/nmi.
- TREPST = Time REPly Starts
- KEBX = Aircraft Reply (Sub-Epoch) Bin indeX - i.e., the number of the bin at the beginning of which the aircraft starts its reply.
- INT(X) = standard FORTRAN function to convert real number X to an integer by truncation (not by rounding off).

The strategy of the above variables is as follows:

The aircraft must begin its reply at the exact beginning of a bin (i.e., bin number KEBX, Time TREPS). Thus the DABS interrogation will generally start (TINTS) somewhere in the middle of a bin. However, it must first be assumed that the interrogation starts at the exact beginning of the first available bin (bin IBX, time TINTST) in order to calculate the number of the first bin in which the aircraft reply could begin (KEBX). (KEBX is the number of the first bin which begins after time TREPST; TREPST is when the reply would start if the interrogation had begun at TINTST.) Once KEBX is established, then TREPS is calculated and supersedes TREPST. TINTS is calculated by working backwards from TREPS; TINTS supersedes TINTST.

- TINTE = Time INTerrogation Ends
- NBINTE = Number of the Bin in which the INTerrogation Ends
- NI = Number of bins or portions of bins used for the Interrogation. For example, if the interrogation starts near the end of the forth bin and ends shortly after the beginning of the eighth bin, NI = 5 (i.e., bins 4,5,6,7, and 8 used).
- TRECS = Time RECeption Starts at the DABS antenna
- TRECE = Time RECeption Ends at the DABS antenna
- KRBX = Reception Bin indeX - i.e., the number of the bin in which the reception of the aircraft's reply begins at the DABS antenna
- NBRECE = Number of the Bin in which the RECeption Ends at the DABS antenna
- NR = Number of bins or portions of bins used for the Reception at the DABS antenna

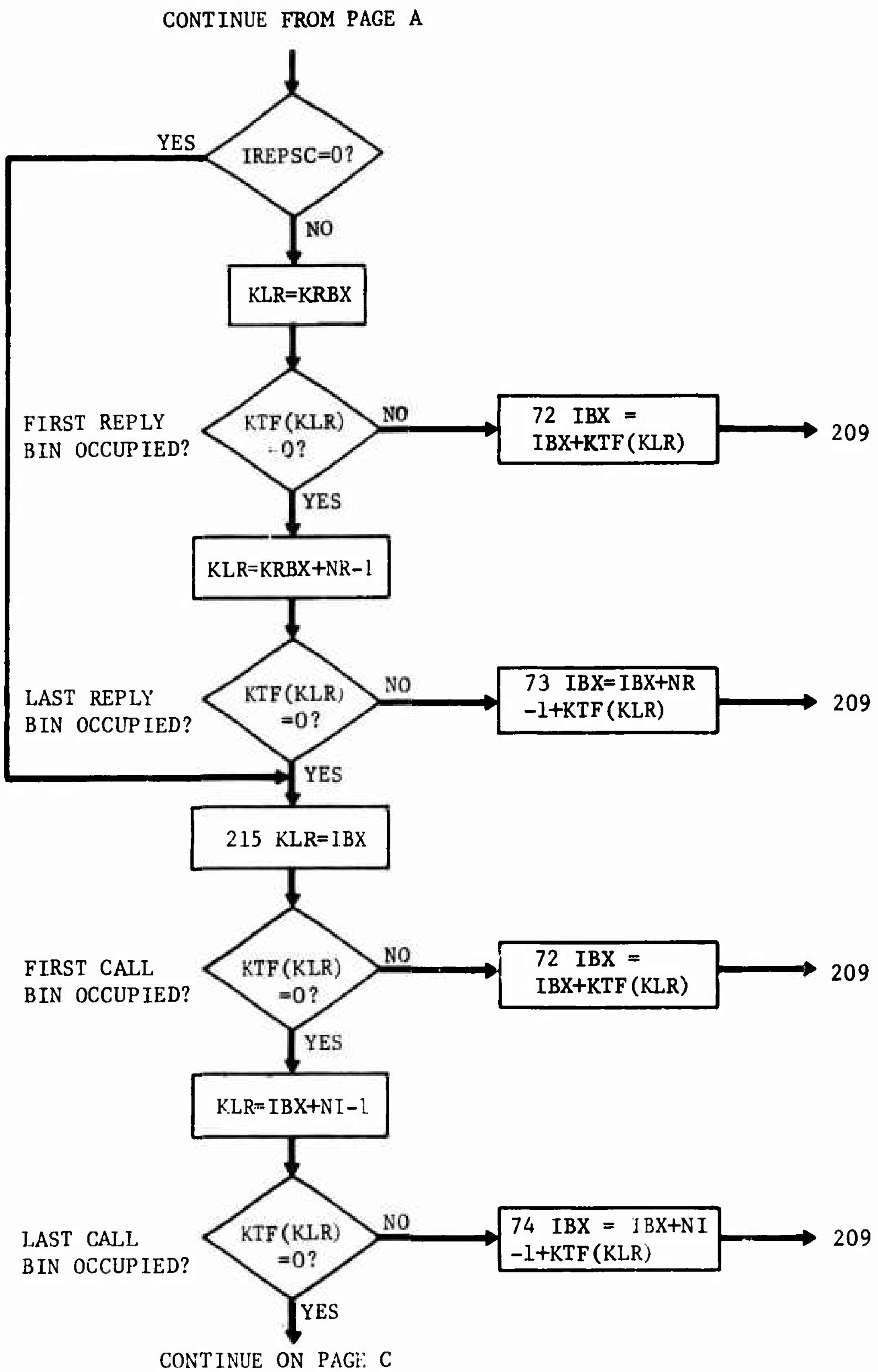
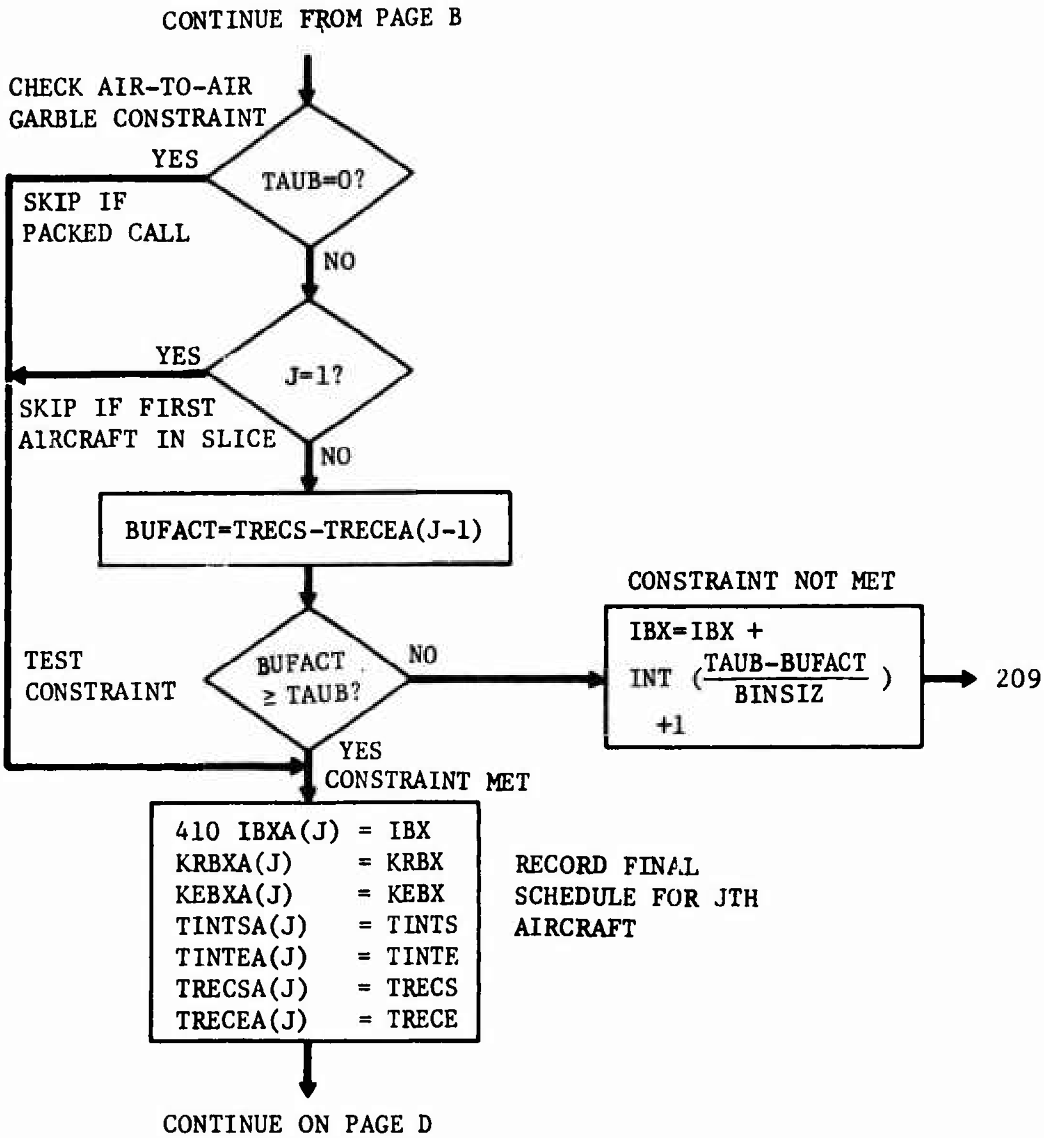


FIGURE A-3 (CONTINUED)
SCHEDULE GENERATOR DETAILED FLOW CHART

(PAGE B)



Notes:

- BUFACT = BUFfer ACTual = time interval between the time the reception starts (Jth aircraft) minus the time the reception ends (J-1 st aircraft). The actual buffer is compared with the minimum required buffer, TAUB.

In FORTRAN there is a syntax rule that if S is the name of a scalar, S cannot also be the name of an array. In this program, the letter A is appended to make the array notation - i.e., SA(J) records the value of S of the J th aircraft as J goes from 1 to N. This is done for seven scalars in the block starting with statement 410 ("Record Final Schedule for J th Aircraft").

FIGURE A-3 (CONTINUED)
SCHEDULE GENERATOR DETAILED FLOW CHART
(PAGE C)

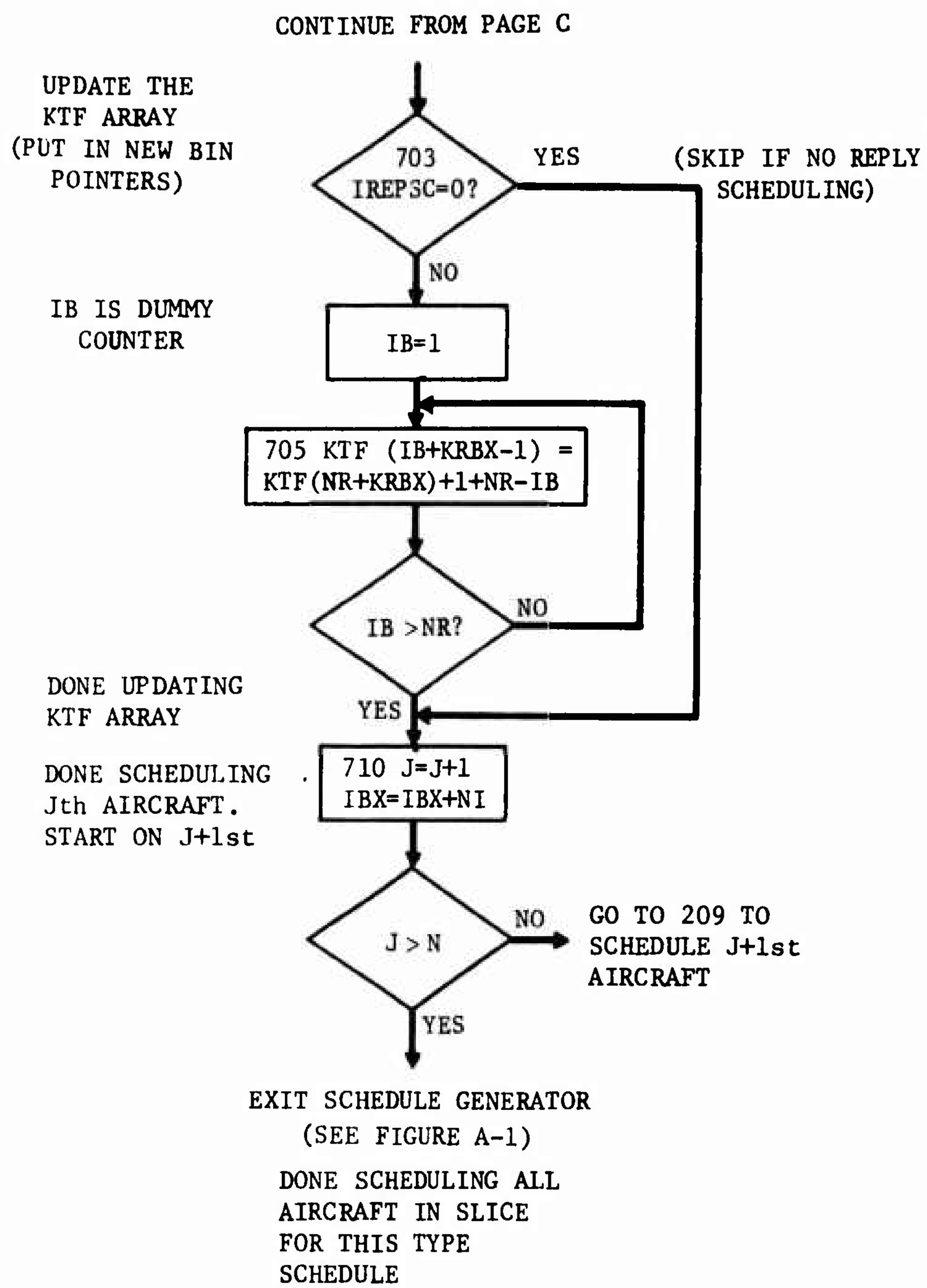


FIGURE A-3 (CONTINUED)
SCHEDULE GENERATOR DETAILED FLOW CHART

(PAGE D)

```
PROGRAM J3SCHED(INPUT,OUTPUT)
DIMENSION R(20),IBXA(20),KRBXA(20),KEBXA(20),KTF(600)
DIMENSION TINTSA(20),TINTEA(20),TRECSA(20),TRECEA(20)
*    START INPUT
PRINT 1510
1510 FORMAT(*INPUT TAUI,TAUR,TAUB,TD,BINSIZ, AND LINTVL UNFORMATTED*)
READ,TAUI,TAUR,TAUB,TD,BINSIZ,LINTVL
TAUBSV=TAUB
IREPSC=1
NOBINS=INT(LINTVL/BINSIZ)
PRINT 1520, NOBINS
1520 FORMAT(//,*NOBINS=*,I5,* -IT IS DIMENSIONED FOR 600*)
1305 PRINT 1310
1310 FORMAT(/,*INPUT N, THE NO. OF A/C IN THE SLICE, UNFORMATTED*)
READ,N
PRINT 1315
1315 FORMAT(/,*INPUT R(J), J=1,N UNFORMATTED*)
*    R(J)S SHOULD BE IN DECREASING RANGE ORDER.
READ, (R(J), J=1,N)
*              INPUT FINISHED
*    SET ALL BIN POINTERS TO 0
1350 DO 1360 NBIN=1,NOBINS
KTF(NBIN)=0
1360 CONTINUE
*              DONE WITH INITIALIZATION
J=1
IBX=1
*    WITH THE TENTATIVE IBX, NOW CALCULATE ALL TIMES ASSOCIATED WITH
*    A/C J. THESE TIMES MAY LATER BE PROVED UNACCEPTABLE, IN WHICH
*    CASE A NEW IBX WILL BE PROPOSED AND SENT BACK TO 209 FOR
*    ANOTHER TRY.
209 TINTST=(IBX-1)*BINSIZ
T1WAY=R(J)*6.18
TREPST=TINTST+T1WAY+TAUI+TD
KEBX=INT(TREPST/BINSIZ)+2
TREPS=(KEBX-1)*BINSIZ
TINTS=TREPS-T1WAY-TAUI-TD
TINTE=TINTS+TAUI
NBINTE=INT(TINTE/BINSIZ)+1
NI=NBINTE-IBX+1
TRECS=TREPS+T1WAY
TRECE=TRECS+TAUR
KRBX=INT(TRECS/BINSIZ)+1
NBRECE=INT(TRECE/BINSIZ)+1
NR=NBRECE-KRBX+1
*   AS PROGRAMMED ABOVE,IF ANY PART OF A BIN IS USED,
*   THE REMAINDER OF THE BIN WILL NOT BE USED.
*        ALL THE ABOVE-CALCULATED TIMES FOR A/C J WILL NOW BE
*        CHECKED TO SEE IF THEY VIOLATE ANY CONSTRAINTS.
IF ( IREPSC .EQ. 0) GO TO 215
*    CHECK BIN AT START OF RECEPTION FOR OVERLAPS.
KLR=KRBX
IF ( KTF(KLR) .NE. 0) GOTO 72
*    CHECK BIN AT END OF RECEPTION FOR OVERLAPS.
KLR=KRBX+NR-1
IF ( KTF(KLR) .NE. 0) GOTO 73
*    CHECK BIN AT BEGINNING OF INTERROGATION FOR OVERLAPS.
215 KLR=IBX
IF ( KTF(KLR) .NE. 0) GOTO 72
*    CHECK BIN AT END OF INTERROGATION FOR OVERLAPS.
KLR=IBX+NI-1
IF ( KTF(KLR) .NE. 0) GOTO 74
```

```
     AIR-TO-AIR GARBLE CONSTRAINT TEST -
     ( SKIP IF PACKED CALL OR FIRST A/C .)
IF ( TAUB .EQ. 0.0) GOTO 410
IF ( J .EQ. 1) GOTO 410
BUFACT=TRECS-TRECEA(J-1)
   CHECK TO SEE THAT ACTUAL BUFFER .GE. REQUIRED BUFFER.
IF ( BUFACT .GE. TAUB) GOTO 410
IBX=IBX+INT((TAUB-BUFACT)/BINSIZ)+1
GOTO 209
                 RECORD THE FINAL RESULTS FOR THE J-TH A/C
   IF YOU GET TO 410, EVERYTHING IS OK FOR A/C J SCHEDULE,
   SO RECORD THE RESULTS FOR A/C J.
410 IBXA(J)=IBX
KRBXA(J)=KRBX
KEBXA(J)=KEBX
TINTSA(J)=TINTS
TINTEA(J)=TINTE
TRECSA(J)=TRECS
TRECEA(J)=TRECE
        UPDATE THE KTF ARRAY (PUT IN NEW BIN POINTERS),
        EXCEPT DONT BOTHER IF NO REP. SCHEDULING.
703 IF ( IREPSC .EQ. 0) GO TO 710
IB=1
705 KTF(IB+KRBX-1)=KTF(NR+KRBX)+1+NR-IB
IB=IB+1
IF ( IB .LE. NR) GO TO 705
    DONE WITH A/C J, NOW DO A/C J+1
710 J=J+1
IBX=IBX+NI
IF ( J .GT. N) GO TO 321
GO TO 209
   THREE QUICK IN-AND-OUTS--ONLY ENTERED FROM GO TO STATEMENTS
   IF A CONSTRAINT WAS VIOLATED. THEY PICK A NEW IBX AND CYCLE
   BACK TO 209 TO TRY THE NEW IBX.
72 IBX=IBX+KTF(KLR)
GO TO 209
73 IBX=IBX+NR-1+KTF(KLR)
GO TO 209
74 IBX=IBX+NI-1+KTF(KLR)
GO TO 209
                 END OF THREE QUICK IN-AND-OUTS
   PREPARE FOR NEXT TYPE SCHEDULE (I.E. SYN CALL W REP. SCH.,
   SYN CALL W/O REP. SCH., PACKED CALL) AND PRINT RESULTS
   OF COMPLETED TYPE SCHEDULE.
321 CONTINUE
   IF WE JUST FINISHED A SYN CALL W REP. SCH., GO TO 356--SYN CALL
   W/O REP. SCH.,GO TO 361,-- PACKED CALL. GO TO 366.
IF (TAUB .GT. 0.0 .AND. IREPSC .EQ. 1) GOTO 356
IF (TAUB .GT. 0.0 .AND. IREPSC .EQ. 0) GOTO 361
IF (TAUB .EQ. 0.0 .AND. IREPSC .EQ. 1) GOTO 366
  YOU ONLY GET HERE IF THERE IS AN ERROR
PRINT 351, TAUB,IREPSC
351 FORMAT(*SNAFU--TAUB,IREPSC FOLLOW*,F10.4,I10)
STOP

356 PRINT 357
357 FORMAT(//*SYNCHRO CALL WITH REPLY SCHEDULING FOLLOWS*/)
   SET UP FOR A SYN CALL W/O REP. SCH. NEXT.
IREPSC=0
IGOTO=1
GO TO 329

361 PRINT 362
362 FORMAT(//*SYNCHRO CALL WITHOUT REPLY SCHEDULING FOLLOWS*/)
   SET UP FOR A PACKED CALL NEXT.
IREPSC=1
```

```
TAUB=0.0
IGOTO=1
GOTO 329
*
366 PRINT 367
367 FORMAT(//*PACKED CALL FOLLOWS - DISREGARD EBX(J) COLUMN*/)
*    SET UP FOR A SYN CALL W REP. SCH. NEXT (IT WILL BE FOR THE
*    NEXT SLICE, IF THERE IS ONE--THIS SLICE IS DONE.)
IREPSC=1
TAUB=TAUBSV
IGOTO=2
GO TO 329
*    THIS PRINT USED FOR ALL 3 TYPES OF CALLS
329 PRINT 330
330 FORMAT(9X,*J*,4X,*IBX(J)*,4X,*EBX(J)*,4X,*RBX(J)*,
+2X,*TINTS(J)  TINTE(J)  TRECS(J)  TRECE(J)*)
PRINT 340,(J,IBXA(J),KEBXA(J),KRBXA(J),TINTSA(J),TINTEA(J),
+TRECSA(J),TRECEA(J), J=1,N)
340 FORMAT(4I10,4F10.2)
*    DONE PRINTING FOR THAT TYPE CALL. GO BACK AND DO NEXT TYPE CALL.
*    IF ALL 3 TYPES ARE DONE (I.E. PACKED CALL JUST FINISHED) GO
*    BACK AND START A NEW SLICE (IF THERE IS ONE).
GO TO (1350,1305), IGOTO
END
```

Notes on the Scheduling Algorithm

(1) The algorithm described in this Appendix is not an optimal solution. Improvements can no doubt be made which will decrease the time required to schedule the traffic. For one thing, this algorithm schedules the aircraft one at a time in decreasing range order. And once an aircraft is scheduled, its schedule is not changed. An optimal scheduler might not follow either of these two strategies, especially for the packed call.

(2) The packed call schedule time is a bit longer than necessary because the algorithm forces each aircraft to begin its response at the exact beginning of a bin. While this is required for synchro calls, it is unnecessary and slightly wasteful for packed calls. This condition was accepted in the initial design of the program but should be redone for an operational computer program. The fix would require less than twenty FORTRAN statements.

(3) If any part of a bin is used, the entire bin is considered used in the current algorithm. A more efficient program would allow a bin to be shared by two calls or receptions, as long as there was no actual overlap at the DABS antenna.

(4) In one example of a scheduled packed call, it was found that notes (2) and (3) above worked in conjunction to unnecessarily force a new cycle (premature by one aircraft). The resultant schedule was 150 μs longer than actually required. This is an unusually large penalty however. A more typical figure might be on the order of 50 μs.

(5) In this program no provision has been made for a range uncertainty buffer. This would be necessary operationally since exact range is not known, and therefore replies would not arrive at the DABS antenna exactly when scheduled. It is felt that a one or two μs buffer between scheduled receptions at the antenna would be sufficient during the packed call. (One μs corresponds to about 1000 feet one way or 500 feet round trip.) This addition to the program would have minimal effect on the results since the buffer is small compared with the reply message length (nominally 64 μs for the packed call). The

range uncertainty buffer would not apply to the synchro call without reply scheduling. It would be required on the synchro call with reply scheduling for air-to-air garble considerations. Note that it would not be required by considerations of reception overlap at the DABS antenna, since the TAUB (nominally 18 μs) is already included between receptions.

A first order approximation of a scheduling algorithm incorporating a reply message length (TAUR) of 64 μs and a range uncertainty buffer of 2 μs would be to use the algorithm of this Appendix (which has no range uncertainty buffer) with a TAUR of 66 μs.

(6) The FORTRAN program schedules a packed call when the schedule generator is entered with TAUB = 0.0. If for some reason it is desired to schedule a synchro call with a TAUB of zero, do not enter TAUB = 0.0 as an input parameter to the program (or it will schedule only packed calls). Instead, enter TAUB = 0.001 μs.

(7) In an operational program, there would have to be a step to check that the scheduled TINTS (Time INTerrogation Starts) is after real time. The program would test if TINTS is greater than or equal to real time plus DELT, where DELT is the minimum response time from scheduler to actual interrogation. If the test is failed, TINTS and IBX would have to be set to a later time so as to just pass the test.

APPENDIX B

SCHEDULING ATCRBS FOR HIGH UPLINK RELIABILITY*

Synchronization of interrogations among neighboring sites is a capability of the DABS system which may enable additional growth features. However, synchronization can cause regions of very low uplink reliability in the ATCRBS mode unless some positive measures are taken to avoid it. This problem can be eliminated by sequentially firing the ATCRBS interrogations so as to achieve high uplink reliability. By high uplink reliability we mean that the uplink reliability would be 100% if it were not for conditions beyond the scheduler's control, such as antenna shielding, ground antenna pattern nulls, DME suppression etc.

It should also be noted that ATCRBS synchronization may not be required outside the high density areas.

This appendix presents an overall program flow chart for an ATCRBS sequential firing time algorithm. The program utilizes site locations (accurate to within a few hundred feet), timing synchronization (accurate to within a μs) and knowledge of the times that each ATCRBS points North (accurate to within 8 μs and called North time) to generate high uplink reliability.

An optimum program would determine the shortest possible time to fire all N sites with high uplink reliability. Such a program would have to look at all N! possible firing sequences and select the one that is the shortest. Because the orientation of each site's mainbeam is changing continuously and somewhat unpredictably, these N! computations would have to be made for each set of ATCRBS firings.

Such a program is considered unrealistic. Instead the program outlined in this appendix looks only at 2N possible firing sequences and generates solutions which are close to optimum.

The polygon in Figure B-1 describes the 2N sequences selected by the program. The polygon's vertices represent the antenna sites and is formed by connecting each antenna site with its nearest neighbor to form edges of the polygon. A sequence selected by the program would be one which starts at a given vertex and traverses either clockwise or counterclockwise the boundary of the polygon. Since there are N such clockwise sequences and an equal number of counterclockwise sequences, a total of 2N sequences are selected.

*This Appendix is a summary of Reference 6.

The program flow chart is given in Figure B-2. The program takes as input the North times of all sites and estimates, for a particular time instant of interest, the azimuth orientation of each site's antenna mainbeam.

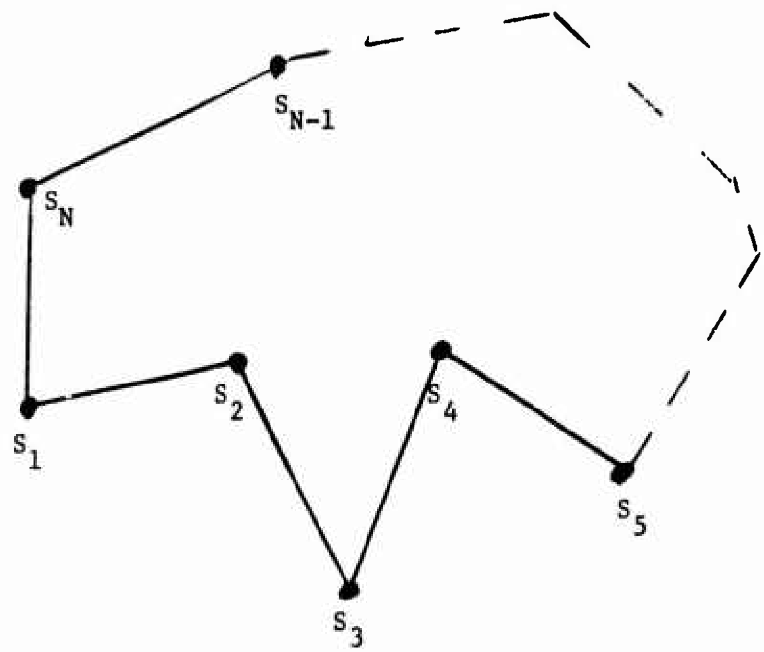
The second task of the program is to determine, for each pair of antennas on the boundary of the polygon (Figure B-1), the minimum time interval between firing times (U_{ij}). This is done independent of the firings of other sites but is constrained by such phenomena as receiver dead-time and sidelobe suppression. It is to be noted that this minimum time is dependent upon which fires first (U_{ij} need not equal U_{ji}).

Once the N^2 ordered site pairs have been computed then the program computes the firing times for all 2N sequences. Here the ordered edge pair firing times are used (2N element subset of set U_{ij}) but second order effects, such as possible sidelobe suppression by site S_i of an aircraft which is being interrogated by site S_{i+2} (not edge paired with S_i) are also accounted for (this utilizes the remaining elements of set U_{ij}).

Once the minimum time to provide high uplink reliability for each of the sequences has been computed the program selects the sequence which gives the minimum time.

Figure B-3 is a detailed version of the Flow Chart given in Figure B-2 and describes all procedures required to determine the geometry and the multiplicity of constraints needed to avoid having a lost uplink response due to sidelobe suppression and receiver dead-time. Table B-1 provides a listing of the definitions of program variables used in the detailed flow chart.

As an example, the program described by Figure B-3 was implemented for the eight sites in the L. A. Basin described by Figure B-4. A Fortran listing of this program is given in Reference 6. The program of Reference 6 will never take more than 1404 μs total firing time. This is within 282 μs of the minimum possible time for any firing order, under the worst case set of interrogator azimuths. Finally, it is noted that the program of Reference 6 can easily be modified and used for any set of eight sites.



S_i = the i^{th} antenna site.

FIGURE B-1

THE N SIDED POLYGON

FIGURE B-2

PROGRAM FLOW CHART

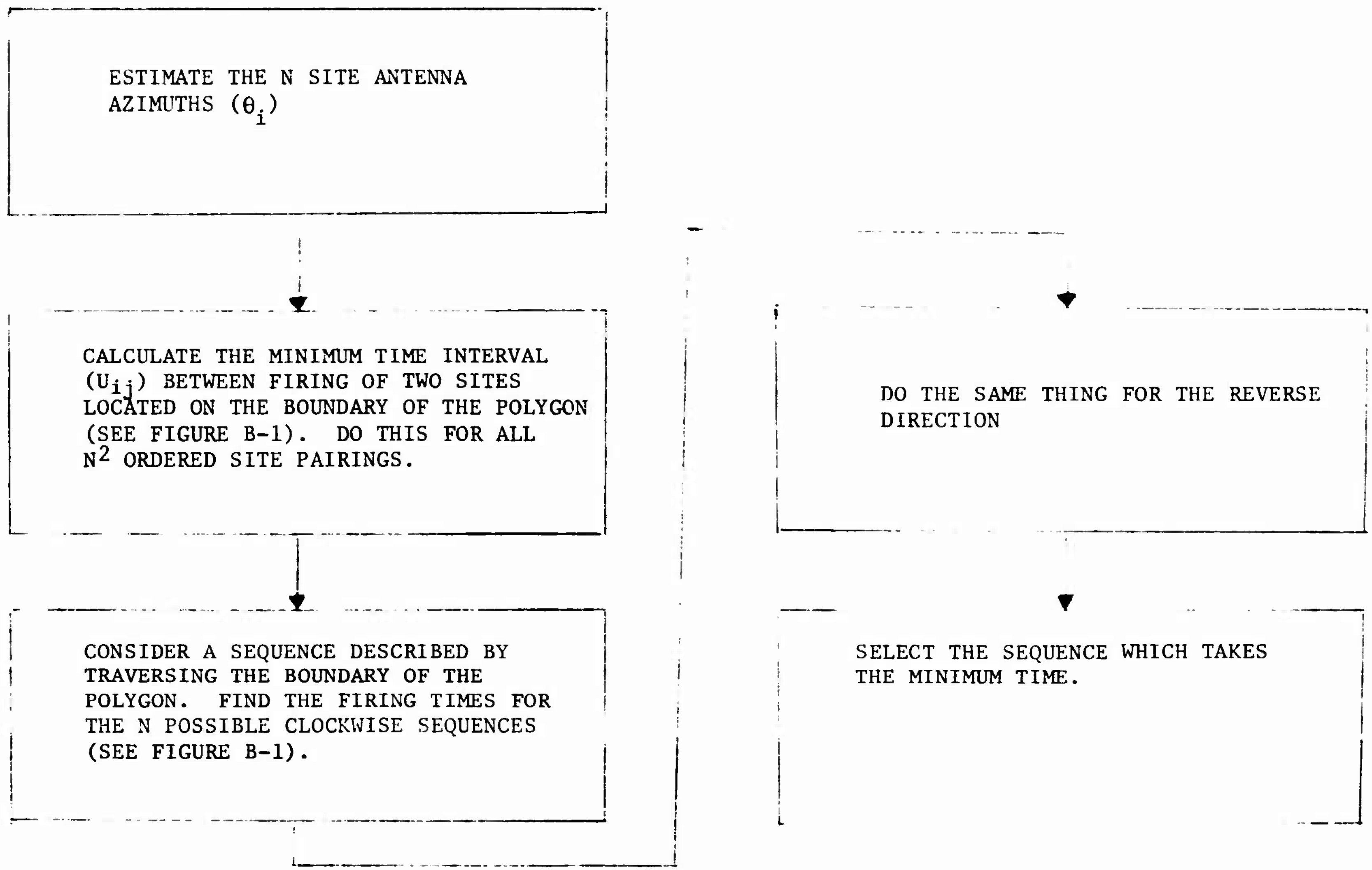


TABLE B-1
DEFINITIONS OF PROGRAM VARIABLES

B-1.1 Site Labeling

The N sites must be labeled by number in a ring (see Figure B-1).

B-1.2 Fixed Matrices

The three fixed NxN matrices used in the program are:

d_{ij} = (distance from site i to site j)/c, where c = .162 nmi/μs

$$TM_{ij} = \begin{cases} 175.68 - d_{ij}, & d_{ij} \le 64.5 \\ d_{ij} + 47, & 64.5 \le d_{ij} \le 185.34 \\ 417.68 - d_{ij}, & 185.34 \le d_{ij} \end{cases}$$

A_{ij} = the angle the line between sites i and j makes with North (note

$A_{ji} = A_{ij} + 180°$)

$i = 1, 2, 3 \ldots.8$ and $j = 1, 2, 3 \ldots. 8$

B-1.3 Input Vectors

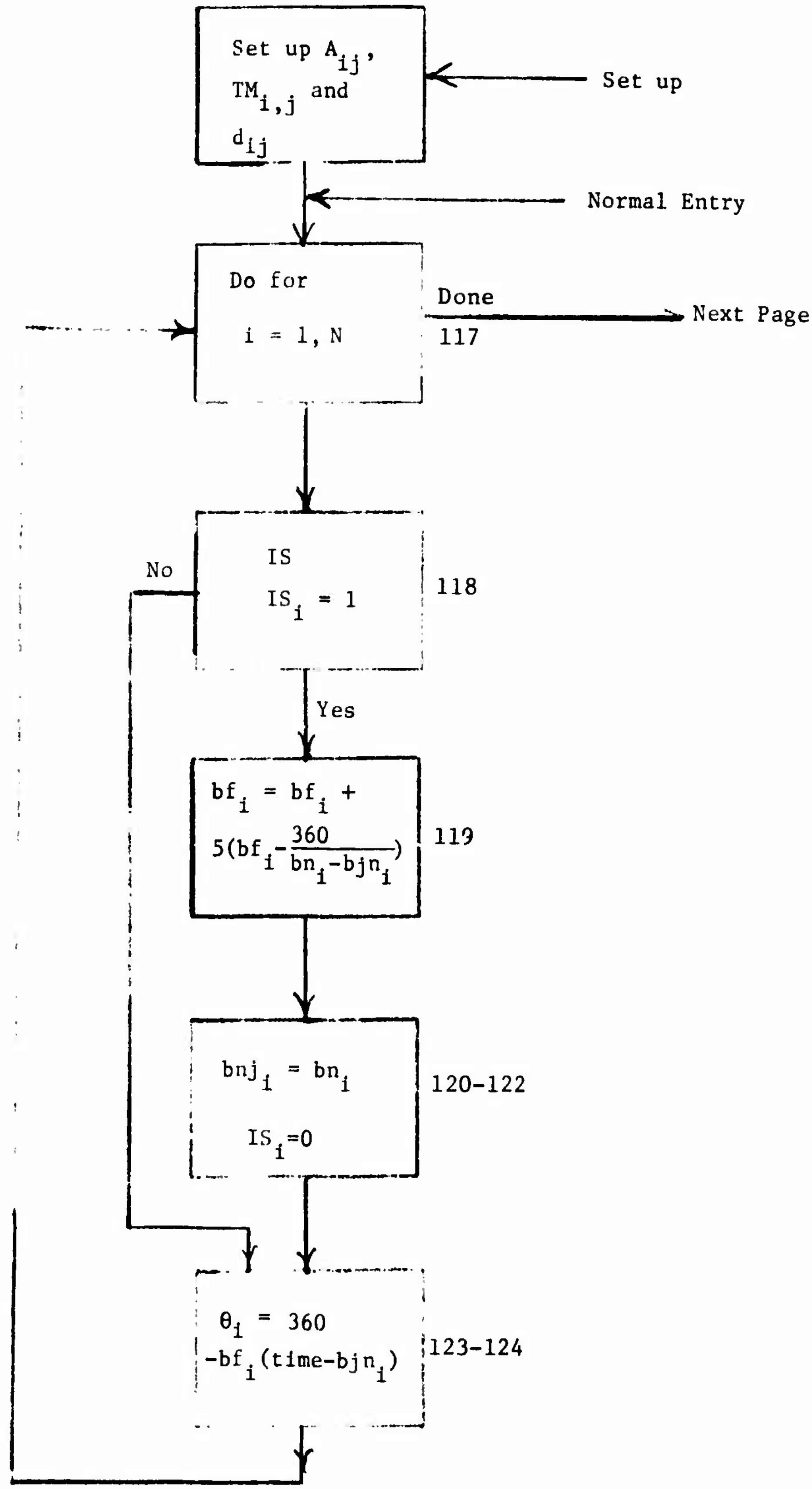
We have 2 variable input vectors TS_i, BN_i which are activated by North time data. Upon the arrival of a North time from site k, that North time is placed in BN_k and IS_k is set to 1. We must also have the time at the start of the firing stored in location TIME.

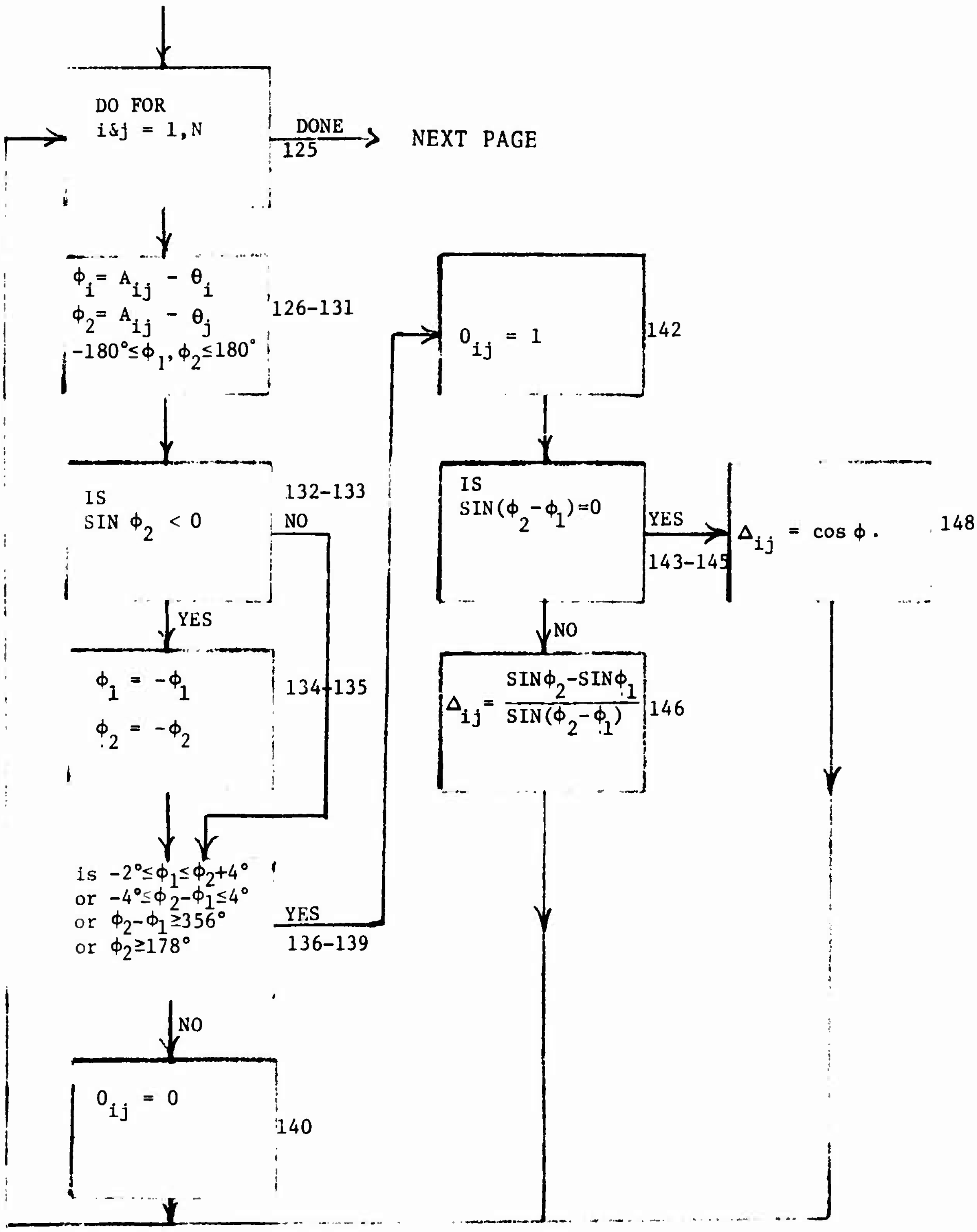
B-1.4 Output Vector

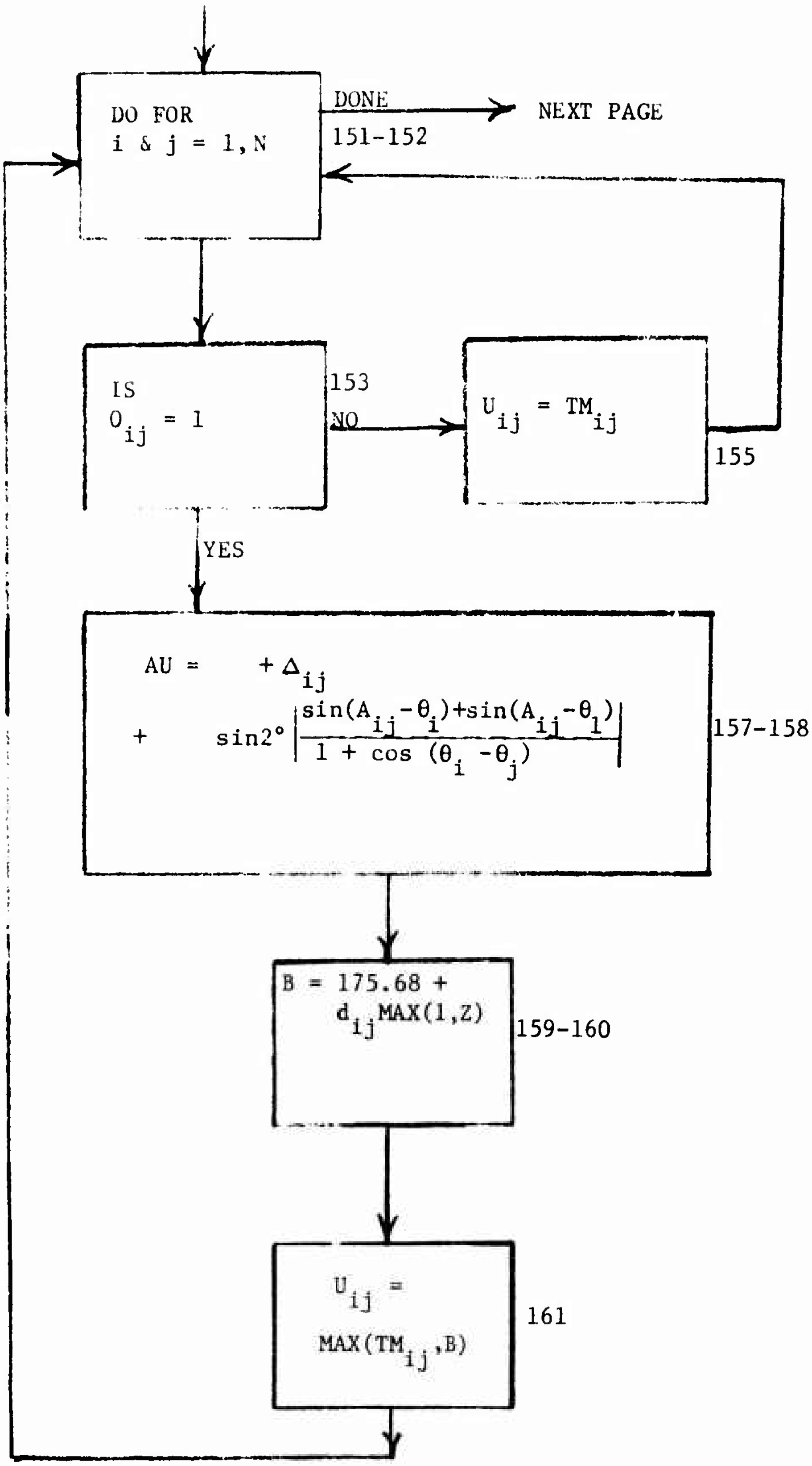
The output firing times are TF_i.

FIGURE B-3

DETAILED FLOW CHART



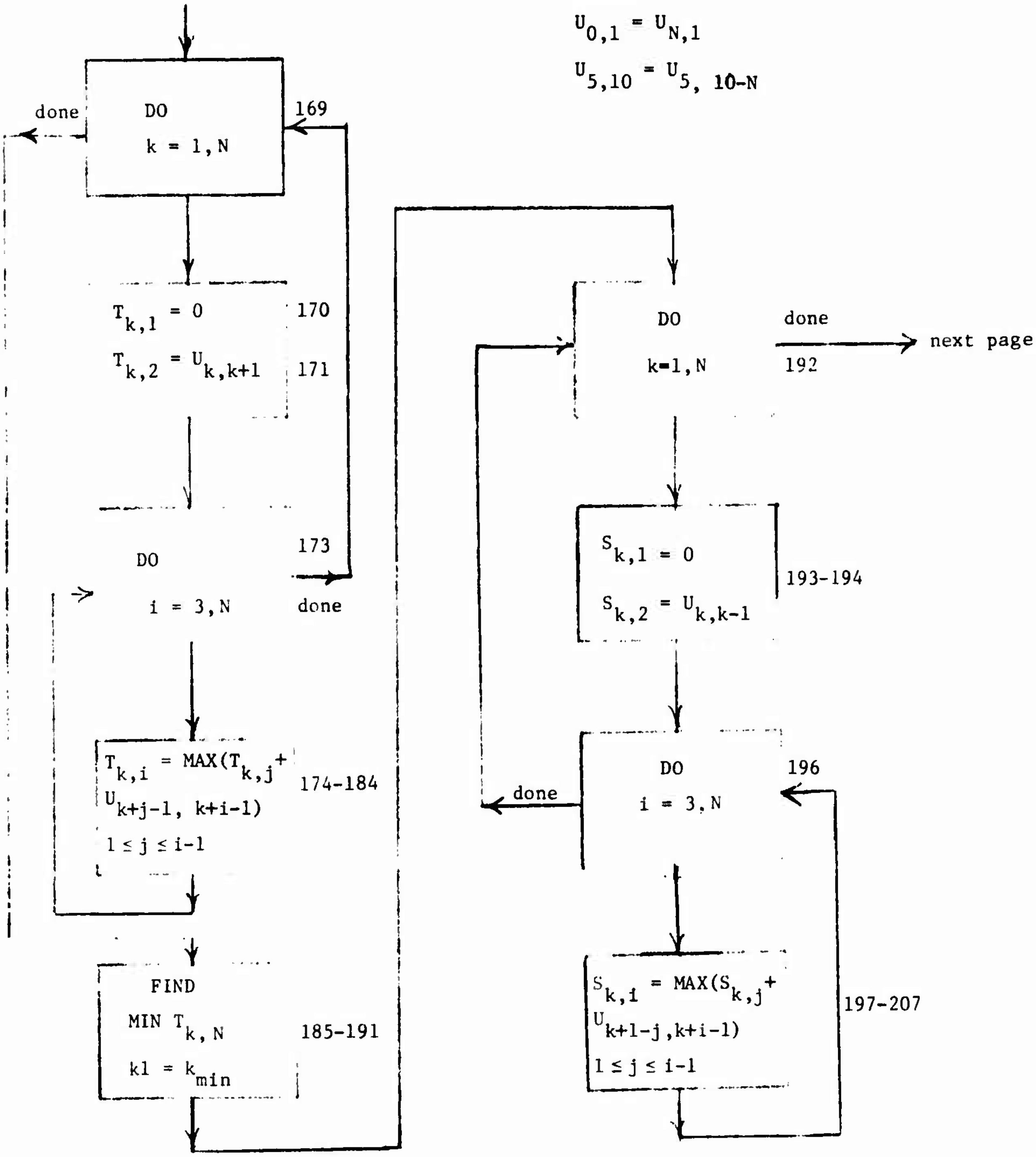

DO FOR
i&j = 1,N
DONE
125
NEXT PAGE
ϕi= Aij - θi
ϕ2= Aij - θj
-180°≤ϕ1,ϕ2≤180°
126-131
IS
SIN ϕ2 < 0
132-133
NO
YES
ϕ1 = -ϕ1
ϕ2 = -ϕ2
134-135
is -2°≤ϕ1≤ϕ2+4°
or -4°≤ϕ2-ϕ1≤4°
or ϕ2-ϕ1≥356°
or ϕ2≥178°
YES
136-139
NO
0ij = 0
140
0ij = 1
142
IS
SIN(ϕ2-ϕ1)=0
YES
143-145
NO
Δij = (SINϕ2-SINϕ1)/SIN(ϕ2-ϕ1)
146
Δij = cos ϕ.
148


DO FOR
i & j = 1,N
DONE
NEXT PAGE
151-152
IS
$O_{ij} = 1$
153
NO
$U_{ij} = TM_{ij}$
155
YES
$AU = \quad + \Delta_{ij}$
$+ \quad \sin 2° \left| \frac{\sin(A_{ij} - \theta_i) + \sin(A_{ij} - \theta_1)}{1 + \cos(\theta_i - \theta_j)} \right|$
157-158
$B = 175.68 + d_{ij} MAX(1,Z)$
159-160
$U_{ij} = MAX(TM_{ij}, B)$
161

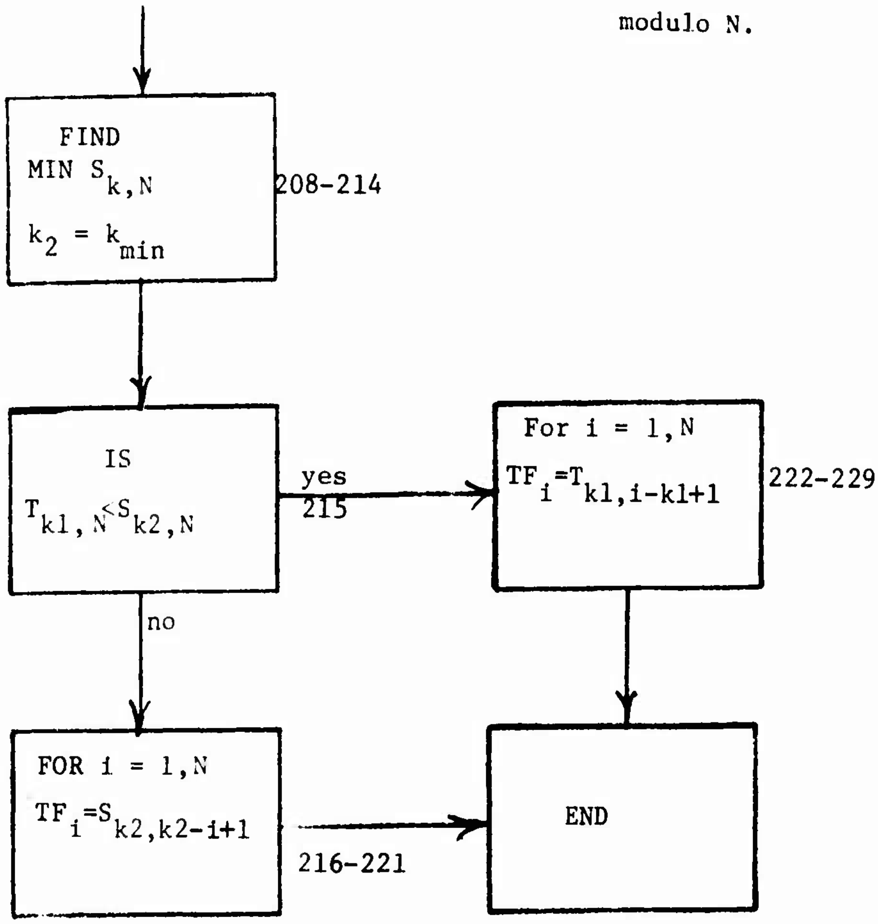
On this page, all indices are modulo N, i.e.

$U_{0,1} = U_{N,1}$

$U_{5,10} = U_{5,\ 10-N}$



On this page, all indices are modulo N.



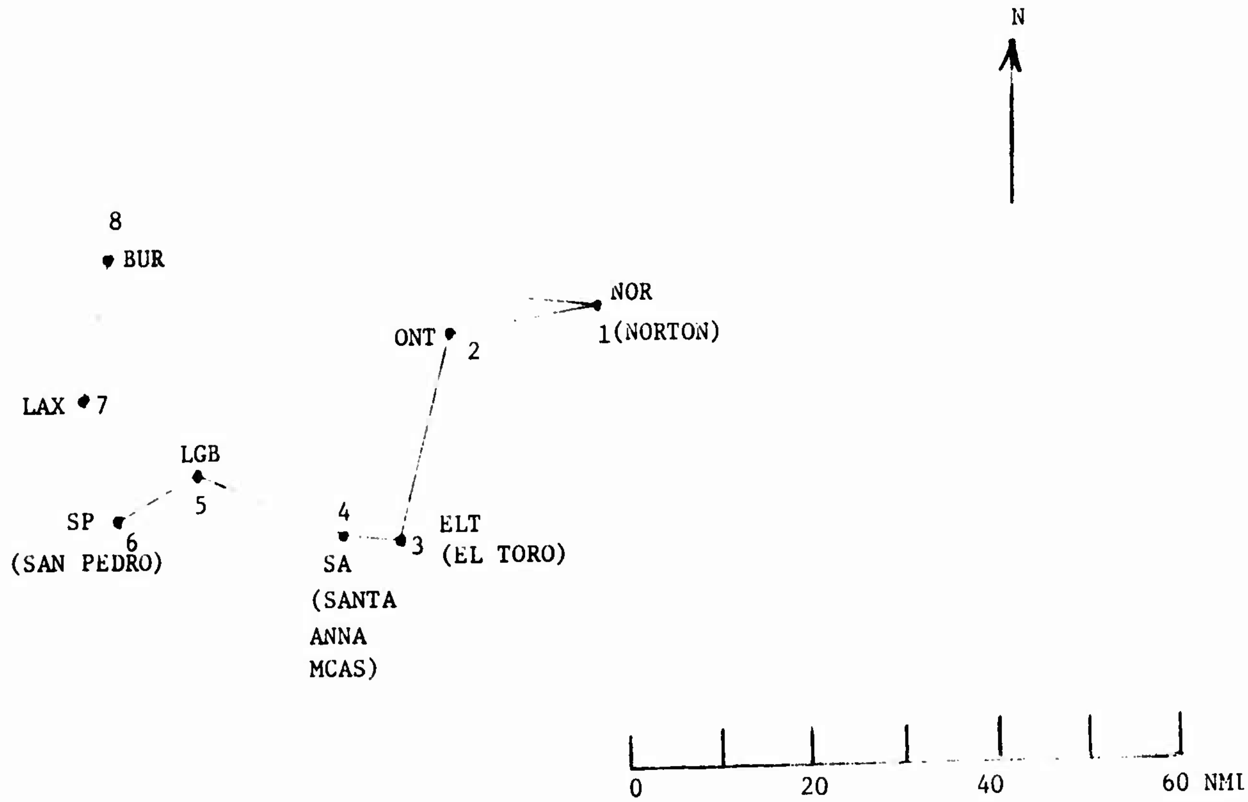


FIGURE B-4
8 SITE L. A. BASIN MODEL

APPENDIX C. SCHEDULING ATCRBS FOR HIGH UPLINK RELIABILITY USING ANTENNA AZIMUTH SYNCHRONIZATION

Appendix B describes the scheduling of ATCRBS for high uplink reliability with all antenna azimuths unrelated. (Antenna azimuths are unrelated in the present system.) That analysis was performed by MITRE and is described in full in Reference 6. Appendix B is a detailed summary of that effort. MITRE was also asked by OSEM to investigate the same problem, but with all ATCRBS antennas synchronized in azimuth. The final report on this study is Reference 5.

The results of the above two studies led OSEM to conclude that the decrease in ATCRBS schedule time offered by the antenna azimuth synchronization did not justify the increased cost and complexity of that system. (Without azimuth synchronization, there was ample time to perform all DABS call/replies, as seen in Chapter II.) Of course, as the DABS design progresses, new requirements may create additional demands for channel time, and azimuth synchronization is one means to gain such time for DABS by cutting ATCRBS requirements.

Since the ATCRBS scheme in this appendix is not recommended for the present design, it will only be briefly summarized here; the interested reader is referred to the MITRE report (Reference 5).

The problem statement is the same as that in Appendix B, except that all antennas rotate with synchronized azimuth. Eight ATCRBS interrogators are included in the L. A. Basin model. For a given azimuth angle, a computer program searches all 40, 320 possible interrogator firing sequences to determine the minimum total firing time. The program then prints out this minimum sequence together with their firing times. There are a total of 28 constraints which must be checked for each interrogator firing order. These constraint tests utilize two 8 x 8 tables generated by the program whose elements indicate how long one must wait to fire interrogator J once interrogator I has fired. The first table is used when the firing of J was immediately preceded by the firing of I. The second table is used when one or more interrogators are fired after I but before J fires.

This program is quite general in that:

1. Any eight site locations can be used.

2. Any transponder suppression and downtime can be used.

3. Any amount of jitter can be used.

4. The performance of a given sequence can be evaluated.

The results show that the maximum time to fire the eight interrogators in the L. A. Basin with high uplink reliability is 761 μs (733 μs delay plus 28 μs jitter). Table C-1 shows the firing sequence and inter-site delays as a function of antenna azimuth. The total ATCRBS schedule time (i. e., the sum of all seven inter-site delays) as a function of azimuth is presented in Chapter II, Figure II-2. Note in both Table C-1 and Figure II-2 that MITRE has defined angles in degrees <u>west</u> -- not east -- of north. Also note for the table and figure that to obtain the firing schedule for angles between 180 and 360 degrees, simply reverse the firing sequence and delays for the reciprocal heading. (See the table's listing for 0 degrees and 180 degrees as an example of this.)

TABLE C-1. ATCRBS FIRING TIMES FOR THE L.A. BASIN

ANGLE*	SEQUENCE								DELAYS μs						
0.0	6	4	2	5	8	1	7	3	10.4	40.2	174.8	41.2	49.9	178.3	31.0
4.0	2	7	6	3	8	1	5	4	130.4	83.9	25.0	123.1	143.9	19.6	7.7
8.0	2	7	5	3	8	1	4	6	130.4	35.9	35.5	112.6	143.9	2.0	1.0
12.0	4	5	1	2	7	6	8	3	7.8	15.6	141.2	136.4	38.9	45.8	113.6
16.0	1	2	7	5	3	8	4	6	141.2	136.4	83.9	56.0	113.6	22.2	15.0
20.0	1	2	7	5	3	8	4	6	141.2	136.4	83.9	65.8	113.6	1.6	23.1
24.0	1	2	7	5	3	4	8	6	141.2	136.4	83.9	75.4	94.6	19.0	11.7
28.0	1	2	7	3	5	4	6	8	141.2	136.4	112.4	151.2	40.1	18.0	6.3
32.0	1	2	7	4	6	3	8	5	141.2	136.4	58.5	45.2	24.1	113.6	140.2
36.0	1	2	7	4	6	3	8	5	141.2	136.4	43.7	52.2	41.7	113.6	148.0
40.0	4	5	6	3	8	1	2	7	[illegible]	50.2	59.2	113.6	143.9	141.2	136.4
44.0	1	2	7	6	3	8	4	5	141.2	136.4	79.1	76.3	113.6	123.0	25.0
48.0	1	2	4	7	6	3	8	5	141.2	135.0	1.4	70.0	93.1	113.6	148.0
52.0	1	2	4	5	7	6	3	8	44.1	118.9	57.1	134.8	60.7	109.4	113.6
56.0	8	3	1	2	4	7	5	6	113.6	178.5	38.1	108.5	31.7	217.6	9.8
60.0	8	3	1	2	4	5	7	6	113.6	184.6	32.0	99.9	88.2	154.4	41.1
62.0	8	3	1	2	4	5	7	6	113.6	187.8	28.9	95.5	95.7	159.5	36.0
64.0	1	8	3	2	4	5	7	6	143.9	125.1	79.3	71.8	103.1	164.5	30.9
66.0	8	3	1	2	4	5	7	6	113.6	194.1	22.6	87.2	110.4	169.7	25.6
68.0	8	3	1	2	4	5	7	6	113.6	197.3	19.4	83.2	117.5	174.8	20.7
70.0	8	3	1	2	4	5	7	6	113.6	200.5	16.2	79.5	124.5	180.0	15.5
72.0	1	2	8	3	4	5	7	6	10.9	204.4	113.6	60.4	131.4	185.2	10.3
74.0	8	3	4	5	1	2	7	6	113.6	62.8	130.0	206.9	9.6	172.7	5.1
76.0	3	8	5	1	2	4	6	7	113.6	148.0	205.4	6.4	71.8	158.2	0.1
78.0	8	3	5	1	2	4	6	7	113.6	148.0	202.7	3.1	71.8	158.2	5.4
80.0	2	1	8	3	4	6	5	7	1.2	204.2	113.6	55.8	158.2	51.3	145.1
82.0	8	1	3	2	4	6	5	7	143.9	126.9	29.1	71.8	158.2	56.1	140.3
84.0	6	5	8	1	3	2	4	7	50.9	148.0	142.9	126.9	23.3	71.8	128.3
86.0	6	5	8	1	3	2	4	7	55.6	148.0	142.9	126.9	17.4	71.8	134.6
88.0	6	5	8	1	3	2	4	7	70.2	148.0	142.9	129.8	11.5	71.8	140.7
90.0	6	5	8	1	3	2	4	7	74.7	148.0	143.9	135.7	5.6	71.8	146.4
92.0	6	7	8	3	5	2	1	4	41.3	203.7	113.6	148.0	152.2	19.8	53.8
94.0	6	7	8	3	5	2	1	4	40.3	202.2	113.6	148.0	145.5	23.0	53.8
96.0	6	7	3	8	5	2	1	4	51.3	200.6	113.6	148.0	138.6	26.2	53.8
98.0	6	7	8	3	5	2	1	4	56.1	198.7	113.6	148.0	131.6	29.3	53.8
100.0	6	7	8	3	5	2	1	4	60.9	196.6	113.6	148.0	124.4	32.4	53.8
102.0	6	5	7	8	1	2	3	4	90.8	133.8	115.8	143.9	141.2	29.8	55.8
104.0	6	7	2	8	5	3	1	4	70.3	191.7	113.6	148.0	109.5	38.5	53.8
106.0	6	5	7	8	1	2	3	4	107.2	133.8	109.7	143.9	141.2	41.4	55.8
108.0	6	5	7	2	3	8	1	4	110.7	88.9	125.5	47.1	157.3	143.9	53.8
110.0	6	5	7	8	2	1	3	4	114.1	146.9	103.0	13.6	141.2	126.9	55.8
112.0	6	5	7	8	2	1	3	4	117.3	147.2	99.5	8.2	141.2	126.9	55.8
114.0	5	7	8	2	1	3	4	6	31.9	95.8	2.7	141.2	126.9	55.8	158.2
116.0	5	7	2	8	1	3	4	6	35.9	89.3	2.8	143.9	126.9	55.8	158.2
118.0	7	5	2	3	8	1	4	6	[illegible]	53.6	74.7	129.7	49.9	72.4	158.2
120.0	7	5	2	3	8	1	4	6	[illegible]	45.5	80.0	124.4	46.9	75.3	158.2
122.0	7	5	2	3	8	1	4	6	33.9	37.1	85.2	119.3	43.9	78.3	158.2
124.0	7	5	2	3	8	1	4	6	[illegible]	28.7	91.2	114.2	40.9	81.3	158.2
126.0	6	7	5	2	3	8	1	4	114.6	55.9	20.3	95.2	113.6	37.8	84.4
128.0	6	7	5	2	3	8	1	4	117.9	68.9	11.8	100.0	113.6	34.7	87.6
130.0	6	7	5	2	3	8	1	4	121.0	82.9	3.4	104.7	113.6	31.5	90.7
132.0	5	8	1	7	2	3	4	6	41.0	28.3	178.3	12.3	109.3	78.9	158.2
136.0	5	8	1	2	7	3	4	6	[illegible]	21.8	187.7	7.3	110.8	89.7	158.2
140.0	2	5	7	8	1	3	4	6	33.9	125.9	39.7	15.1	126.9	55.8	158.2
144.0	2	5	7	8	1	3	4	6	55.5	118.9	30.0	8.4	126.9	55.8	158.2
148.0	2	5	7	8	1	3	4	6	71.9	127.8	20.2	1.6	126.9	91.4	71.4
152.0	5	7	1	8	3	4	6	2	137.8	5.1	5.1	121.8	97.6	65.3	60.5
156.0	1	5	7	8	3	4	6	2	12.0	147.7	0.3	113.6	113.6	58.9	44.2
160.0	1	8	7	5	3	4	6	2	13.5	9.7	138.3	38.9	144.6	52.2	27.6
164.0	1	8	7	5	3	4	6	2	25.1	19.6	129.4	28.5	160.6	45.2	10.9
168.0	1	8	7	5	3	4	2	6	31.6	29.4	113.6	17.8	184.5	32.2	5.8
172.0	3	7	1	8	5	4	2	6	4.0	178.3	37.9	27.9	183.5	8.1	22.6
176.0	3	7	1	8	5	2	4	6	17.5	178.3	44.0	34.6	174.8	16.1	23.1
180.0	3	7	1	8	5	2	4	6	31.0	178.3	40.9	41.2	174.8	40.1	15.5

NOTE 1=LAX, 2=[illegible], 3=SP, 4=NOR, 5=SA, 6=ONT, 7=FLT, 8=LGB

* Degrees west of North

APPENDIX D. WORST-CASE SCHEDULE TIME

The problem considered is that of determining the maximum time required to schedule N aircraft in one slice under the constraints that:

1) Target ranges are monotonic decreasing.

2) No calls can overlap.

3) No replies can overlap. (This and the next constraint do not apply to synchro calls without reply scheduling.)

4) No call/reply combination can overlap.

5) All aircraft sub-epochs must be monotonic increasing and separated by a specified buffer (synchro calls only).

The parameters which affect the solution of this problem are:

Call message length	τ_I
Reply message length	τ_R
Buffer time	τ_B
Number of aircraft	N
Transponder Delay*	T_D

An analytical representation of the above constraints is presented below:

1. RANGE ORDER

$$\rho_{ij} = r_i - r_j \geq 0 \; ; \; i < j \tag{1}$$

where r_i is the (slant) range of the i^{th} aircraft, and ρ_{ij} is the range difference between the i^{th} and j^{th} aircraft.

*T_D here is defined as the transponder delay from the trailing edge of the interrogation to the leading edge of the response. (See Appendix A)

2. <u>OVERLAP</u>

$$t_{c_j} \geqslant t_{c_i} + \tau_I \tag{2}$$

where t_{c_i} is the time a site calls the i^{th} aircraft.

3. <u>REPLY OVERLAP</u>

$$\left| t_{R_j} - t_{R_i} \right| \geqslant \tau_R \tag{3}$$

where t_{R_i} is the time a site receives the reply of the i^{th} aircraft.

Note that nesting replies (i.e., $t_{R_j} - t_{R_i} \leqslant -\tau_R$ for $i < j$), where possible, can save schedule time. Thus, by disallowing nesting in this worst-case analysis, one always gets a longer (or equal at best) schedule time. If one lets

$$t_{R_j} - t_{R_i} \geqslant \tau_R \tag{4}$$

as opposed to (3), no nesting can occur. (Note that nesting is allowed in the actual packed call scheduling algorithm, but not in this worst-case analysis.)

4. <u>CALL/REPLY OVERLAP</u>

In the case of one call/reply cycle, there is the constraint that the $i+1^{st}$ reply does not overlap the i^{th} reply and is separated from the i^{th} reply by the buffer time τ_B:

$$t_{R_{i+1}} - t_{c_{i+1}} \geqslant t_{R_i} - t_{R_1} + \tau_R + \tau_I + \tau_B \tag{5R}$$

(Equation 5R above is the reply overlap constraint; Equation 5C below is the call overlap constraint.) No call may overlap the first reply:

$$t_{c_i} + \tau_I \leqslant t_{R_1} \tag{5C}$$

For the start of a new cycle, the first call (i + 1) of the new cycle must begin after the end of the last reply (i) of the previous cycle:

$$t_{c_{i+1}} \geqslant t_{R_i} + \tau_R \tag{6}$$

5. SUB-EPOCH SPACING

Aircraft j is at a closer range in the slice than aircraft i ($i < j$). Aircraft j cannot be scheduled to transmit until aircraft i's transmission has passed (plus a buffer, τ_B - see Appendix A). This is known also as the "expanding ring" constraint:

$$t_{T_j} - t_{T_i} \geq \frac{\rho_{ij}}{c} + \tau_R + \tau_B \tag{7}$$

where t_{T_i} is the transmit time of the i^{th} aircraft; c is the speed of light. Note

$$t_{T_i} = t_{c_i} + \frac{r_i}{c} + \tau_I + T_D \tag{8}$$

The above eight equations contain a combination of call times, aircraft transmit times, and reply received times (t_c, t_T, and t_R, resp.). The constraint equations will now be rewritten in terms of t_R only; t_c can be eliminated by using:

$$t_{c_i} = t_{R_i} - \frac{2}{c} r_i - \tau_I - T_D \tag{9}$$

Also, the i, j notation will be replaced by an i, i + 1 notation. Thus, the constraints can be rewritten as:

1. RANGE ORDER - Equation 1 becomes:

$$\rho_{i,i+1} = r_i - r_{i+1} \geq 0 \tag{10}$$
$$i = 1, 2, \ldots, N-1$$

2. CALL OVERLAP - Equation 2 becomes:

$$t_{R_{i+1}} - t_{R_i} \geq \tau_I + \frac{2}{c}(r_{i+1} - r_i)$$

Since $(r_{i+1} - r_i)$ is always nonpositive, we have:

$$t_{R_{i+1}} - t_{R_i} \geq \tau_I \tag{11}$$

3. REPLY OVERLAP AND NESTING - Equation 4 becomes:

$$t_{R_{i+1}} - t_{R_i} \geq \tau_R \tag{12}$$

4. CALL/REPLY OVERLAP

Equation 9 is substituted into Equation 5R. The 1 (one) subscript (first aircraft in the range ordering) is replaced by the K subscript, where K denotes the first aircraft in any cycle of the range ordering. The resulting equation applies only to aircraft within the same single cycle:

$$t_{R_i} - t_{R_K} \leqslant \frac{2}{c} r_{i+1} + T_D - \tau_R - \tau_B \tag{13R}$$

Equation 9 is now substituted into Equation 5C. Again the "within cycle" restriction applies:

$$t_{R_i} - t_{R_K} \leqslant \frac{2}{c} r_i + T_D \tag{13C}$$

Equation 9 substituted into Equation 6 yields Equation 14, below. Note that this equation governs the start of a new cycle; aircraft i + 1 is the first in the new cycle, and aircraft i is the last in the previous cycle.

$$t_{R_{i+1}} - t_{R_i} \geqslant \frac{2}{c} r_{i+1} + \tau_I + \tau_R + T_D \tag{14}$$

5. SUB-EPOCH SPACING

Replies must not overlap anywhere in space, including at the DABS antenna, and in addition there must be a buffer between successive receptions at the antenna:

$$t_{R_{i+1}} - t_{R_i} \geqslant \tau_R + \tau_B \tag{15}$$

All constraints are now in terms of the same variables. Further inspection will lead to the discarding of some constraints. Note that in general for the DABS design parameters used:

$$\tau_I \leqslant \tau_R \tag{16}$$

$$\tau_B \geqslant 0 \tag{17}$$

Thus, if Equation 15 is satisfied, Equations 11 and 12 will also be satisfied. Therefore, the maximum schedule time will be achieved by

imposing Equations 10, 13R, 13C, 14, and 15 as constraints.* Note that in the case of a synchro call where replies are not scheduled for reception at the DABS antenna, Equations 13R, 13C, and 14 do not apply.

Note that for maximum schedule time given the same target ranges, N, τ_R, τ_I, τ_B, T_D, the sub-epoch spacing constraint dominates, which implies that a synchro call with reply scheduling will always be longer than a packed call schedule. Remember, however, that in this simulation a larger value of τ_R was used for packed calls than for synchro calls. For the values used, the packed calls generally required more time.

Based upon the above constraint analysis, it is now possible to construct models for the schedule time in terms of the problem parameters.

CYCLE LENGTH

A cycle is defined as a group of interrogations followed by a group of replies. A new cycle starts when a new set of interrogations begins after a set of replies has been received. Based upon the constraint analysis presented above, a cycle of n aircraft will appear as illustrated in Figure D-1, and the equations governing the cycle are given by:

$$\Delta_1 = \frac{2}{c}(r_1 - r_2) + (\tau_R + \tau_B) - \tau_I$$

$$\Delta_2 = \frac{2}{c}(r_2 - r_3) + (\tau_R + \tau_B) - \tau_I$$

$$\Delta_i = \frac{2}{c}(r_i - r_{i+1}) + (\tau_R + \tau_B) - \tau_I \qquad (18)$$

$$\Delta_{n-1} = \frac{2}{c}(r_{n-1} - r_n) + (\tau_R + \tau_B) - \tau_I$$

$$\Delta_n = \frac{2}{c} r_n - (n-1)(\tau_R + \tau_B) + T_D$$

$$\sum_{i=1}^{n} \Delta_i = \frac{2}{c} r_1 - (n-1)\tau_I + T_D \qquad (19)$$

*It is noted that Equation 13R is dependent on Equations 13C and 15. However, the derivation seems more convenient when done in the above fashion.

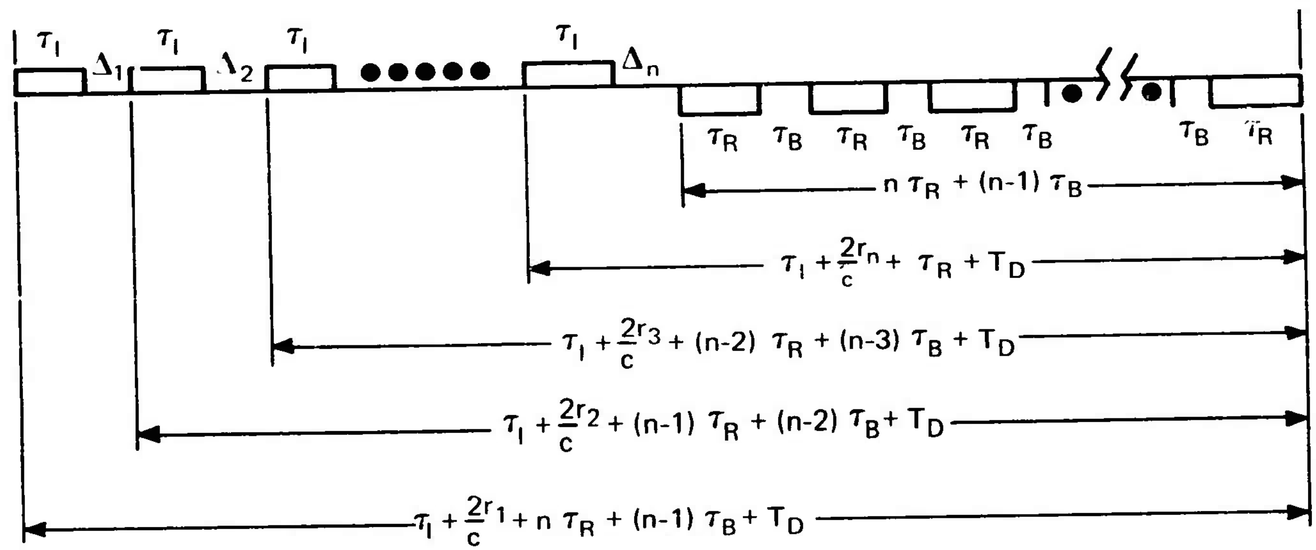


Figure D-1. Cycle Timing

As seen from the figure, the cycle time of the j^{th} cycle is given by

$$T_j = n_j \tau_R + (n_j-1)\tau_B + \tau_I + \frac{2}{c} r_{1+n_1+\ldots+n_{j-1}} + T_D \qquad (20)$$

where n_j is the number of aircraft in the j^{th} cycle and $r_{1+n_1+\ldots+n_{j-1}}$ is the range of the first aircraft in the j^{th} cycle. The total schedule time is thus given by

$$T_S = \sum_{j=1}^{L} T_j \qquad (21)$$

where L is the number of cycles.

Performing the indicated summation and noting that

$$N = n_1 + n_2 + \ldots + n_L \qquad (22)$$

one obtains

$$T_S = N\tau_R + (N-L)\tau_B + L(\tau_I + T_D) + \frac{2}{c}\left[r_1 + r_{1+n_1} + \ldots + r_{1+n_1+\ldots+n_{L-1}}\right] \qquad (23)$$

The last term on the right of Equation 23 must be replaced by an expression containing only known parameters of the problem, which form an upper bound. This can be done using Equation 13R. 13R, as written, applies within a single cycle (i.e., aircraft K, i, and i+1 are all in the same cycle). With the inequality reversed, 13R governs the beginning of a new cycle (i.e., aircraft K and i are the first and last aircraft, resp., of the old cycle, and aircraft i+1 is the first of a new cycle). 13R can now be rewritten accordingly. To be compatible with Equation 23, the subscripts are replaced by the newer notation: Subscript $(1+n_1+\ldots+n_{j-1})$ denotes the first aircraft in the j^{th} cycle, $(n_1+\ldots+n_{j-1})$ denotes the last aircraft in the $j-1^{st}$ cycle, and $(1+n_1+\ldots+n_{j-2})$ denotes the first aircraft in the $j-1^{st}$ cycle. Thus we have Equation 24, governing the start of the j^{th} cycle:

$$t_{R_{n_1+\ldots+n_{j-1}}} - t_{R_{1+n_1+\ldots+n_{j-2}}} > \frac{2}{c} r_{1+n_1+\ldots+n_{j-1}} + T_D - \tau_R - \tau_B \qquad (24)$$

The left hand side of (24) is simply the time interval between the start of the last and first replies of the $j-1^{st}$ cycle: from Figure D-1 it can be seen that

$$t_{R_{n_1+\ldots+n_{j-1}}} - t_{R_{1+n_1+\ldots+n_{j-2}}} = (n_{j-1} - 1)(\tau_R + \tau_B) \qquad (25)$$

The above substituted into Equation 24 gives:

$$n_{j-1}(\tau_R + \tau_B) - T_D > \frac{2}{c} r_{1+n_1+\ldots+n_{j-1}} \tag{26}$$

$$\text{for } j=2,\ldots,L$$

Substituting the above into Equation 23 gives an upper bound to the maximum schedule time T_S :

$$T_S < N\tau_R + (N-L)\tau_B + L(\tau_I + T_D) + \frac{2}{c} r_1 + \sum_{j=2}^{L}\left\{n_{j-1}(\tau_R + \tau_B) - T_D\right\} \tag{27}$$

If we define $T_{S_{max}}$ to be the limit, the less than sign is replaced by the equality. Equation 22 is used to evaluate the summation; and terms are collected giving:

$$T_{S_{max}} = 2N(\tau_R + \tau_B) - n_L(\tau_R + \tau_B) + L(\tau_I - \tau_B) + T_D + \frac{2}{c} r_1 \tag{28}$$

L and n_L above are not known until the actual schedule has been generated for a particular slice, so they must be replaced by known quantities. This must be done in such a way as to obtain the maximum value of $T_{S_{max}}$. This is accomplished by inspection in two steps. First, since τ_R and τ_B are both nonnegative, n_L must be set to its minimum value of 1. Second, since τ_I exceeds τ_B (at least in all cases considered in this report), L must be set to its maximum value of N. This is required for Equation 28 to hold for general values of the system parameters. However, for the actual system parameters used in the LA Basin simulation, L was normally found to be about one quarter of N. This causes the result to be somewhat conservative. Substituting for n_L and L and rearranging terms gives:

$$T^{(1)}_{S_{max}} = (2N-1)\tau_R + N\tau_I + (N-1)\tau_B + T_D + \frac{2}{c} r_1 \tag{29}$$

which is valid for packed calls and synchro calls with reply scheduling. Using the system parameters from Table A-1 for the packed call, Equation 29 becomes:

$$T^{(1)}_{S_{max}} = 182N + 12.36 r_1 + 10 \tag{30}$$

For the synchro call without reply scheduling, there is always one and only one cycle, so L=1 and n_L=N. Substituting these values into Equation 28 gives the maximum scheduling time for the synchro call without reply scheduling:

$$T_{S_{max}}^{(2)} = N\,(\tau_R + \tau_B) - \tau_B + \tau_I + T_D + \frac{2}{c}\,r_1 \qquad (31)$$

This same result could also be obtained from inspection of Figure D-1. Note that this allows time for all aircraft replies to return to and clear the DABS antenna even though the antenna is not listening to the replies. This is done so that when several sites' synchro call intervals follow consecutively, the reply of the last aircraft called by one site will not garble the reply of the first aircraft called by the following site, as discussed in Chapter II.

Substituting the system parameters of Table A-1 into Equation 31 gives the following for the synchro call without reply scheduling:

$$T_{S_{max}}^{(2)} = 54N + 12.36r_1 + 110 \qquad (32)$$

It is noted without presenting the derivation that for the synchro call without reply scheduling, the maximum time required to schedule all N interrogations (i.e., from the beginning of the first interrogation to the end of the N^{th} interrogation) is

$$T_{S_{max}}^{(3)} = (N-1)\,(\tau_R + \tau_B) + \tau_I + \frac{2}{c}\,(r_1 - r_N) \qquad (33)$$

It should be pointed out that the above analysis does not take into account the fact that for synchro calls all aircraft replies must start at the beginning of a sub-epoch (bin). Thus, for synchro calls the result may be unconservative by an amount averaging approximately N times half of the bin size (N x BINSIZ/2). However, the conservative factor discussed just before Equation 29 averages approximately 0.75N (τ_I - τ_B), which is larger than the above unconservative effect by a factor of 4.5 for the system parameters used.

In any case, the usefulness of the analysis is borne out by the fact that the theoretical maximums were not exceeded for the large numbers of slices scheduled in the four site model, the eight site model, and the four separate failure mode cases of the four site model.

APPENDIX E. AIR-TO-AIR GARBLE

The problem which is addressed in this appendix is that of determining the magnitude of the buffer required between call intervals such that a garble free zone of radius ρ is guaranteed around any aircraft while operating in a Synchro DABS mode. The geometry of aircraft and site positions is presented as Figure E-1 and the concept of a buffer between call intervals by Figure E-2.

NOMENCLATURE

r	=	range (minimum)
t_i	=	time aircraft i transmits
t_j	=	time aircraft j transmits
t_{ki}	=	time aircraft k hears end of i transmission
t_{kj}	=	time aircraft k hears end of j transmission
T_1	=	length of site call interval
δ	=	buffer time
τ_I	=	interrogation message length
τ_R	=	reply message length
t_{1i}	=	time DABS site 1 calls aircraft i
t_{2j}	=	time DABS site 2 calls aircraft j
T_D	=	transponder delay as defined in Appendix A

CONSIDER THAT:

$$t_i = r_{1i} \times 6.18 + \tau_I + t_{1i} + T_D \qquad (1)$$

$$t_j = r_{2j} \times 6.18 + \tau_I + t_{2j} + T_D \qquad (2)$$

Aircraft k hears the end of the transmission of aircraft i

$$t_{ki} = t_i + r_{ik} \times 6.18 + \tau_R \qquad (3)$$

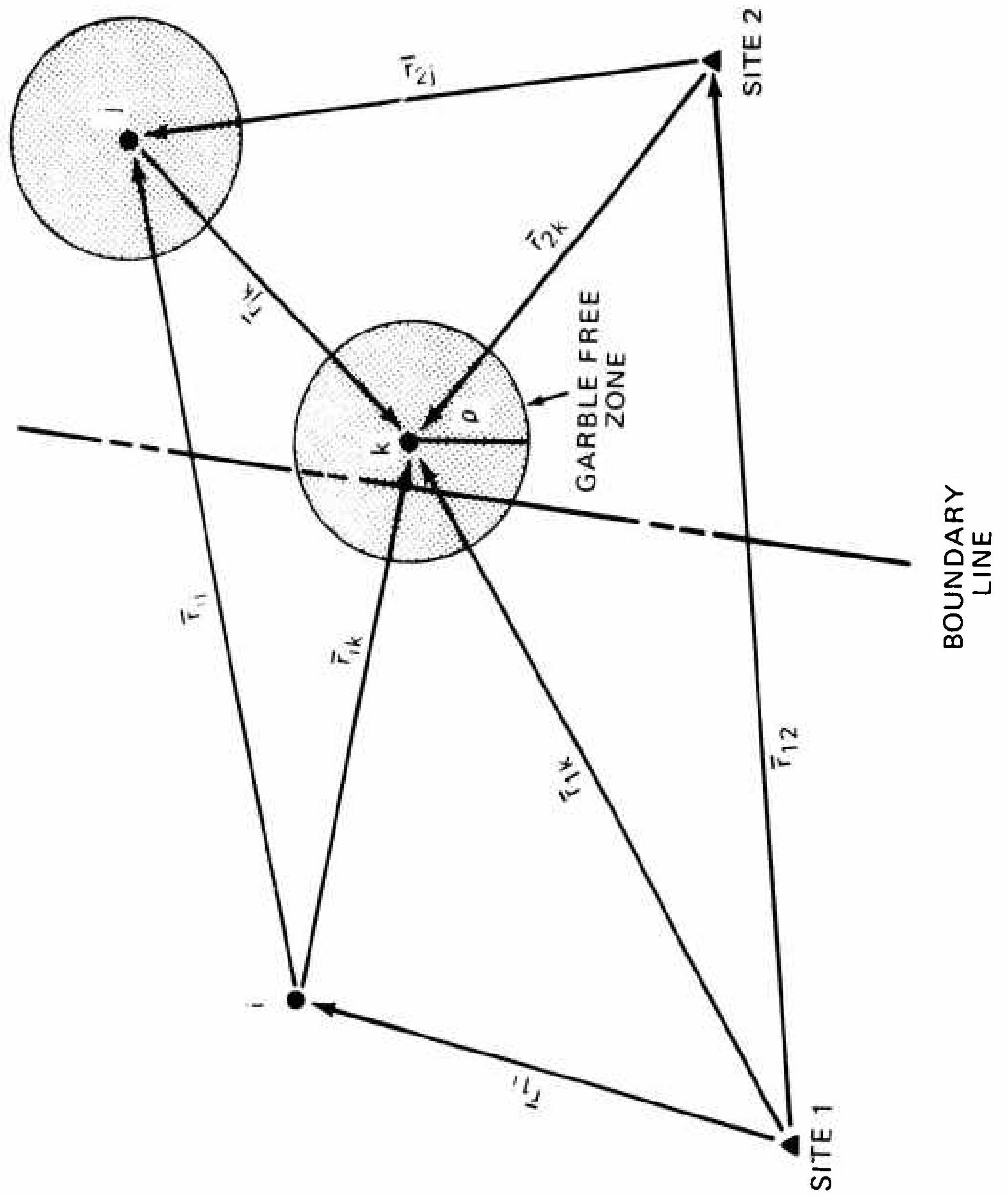


Figure E-1 GARBLE GEOMETRY

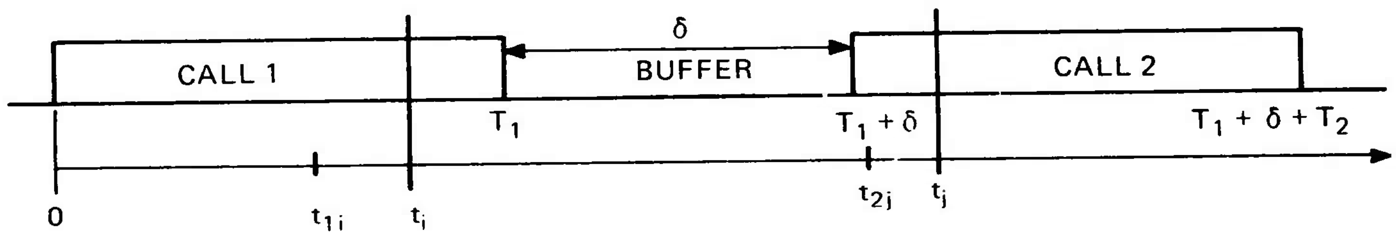


Figure E-2. Call/Buffer Timing

and the end of the transmission of aircraft j at

$$t_{kj} = t_j + r_{jk} \times 6.18 + \tau_R \tag{4}$$

Now, by substitution of (1) into (3), and (2) into (4)

$$t_{ki} = (r_{1i} + r_{ik}) \times 6.18 + \tau_R + \tau_I + t_{1i} + T_D \tag{5}$$

$$t_{kj} = (r_{2j} + r_{jk}) \times 6.18 + \tau_R + \tau_I + t_{2j} + T_D \tag{6}$$

Substracting (5) from (6) yields

$$t_{kj} - t_{ki} = \left[(r_{2j} - r_{1i}) + (r_{jk} - r_{ik})\right] \times 6.18 + (t_{2j} - t_{1i}) \tag{7}$$

Also, substracting (1) from (2) note that

$$t_j - t_i = (r_{2j} - r_{1i}) \times 6.18 + (t_{2j} - t_{1i}) \tag{8}$$

Substituting (8) into (7) yields

$$t_{kj} - t_{ki} = t_j - t_i + (r_{jk} - r_{ik}) \times 6.18 \tag{9}$$

Next consider that:

r_M = closest range to a DABS site that a target will be called so that the latest time target i could transmit during the site #1 interval is (see Figure E-2) $t_i = T_1 - r_M \times 6.18 - \tau_R$ (10)

Note this assumes that replies are scheduled for ground reception.

The earliest time a target could transmit during the site #2 interval is

$$t_j = T_1 + \delta + r_M \times 6.18 + \tau_I + T_D \tag{11}$$

Subtraction of (10) from (11) yields

$$t_j - t_i = \delta + 2r_M \times 6.18 + \tau_I + \tau_R + T_D \tag{12}$$

The condition that k be garble free is given by

$$\left| t_{kj} - t_{ki} \right| \geq \tau_R + \Delta \tag{13}$$

where Δ is to be considered an optional buffer for the moment.

From (9) and (13) one obtains

$$\left| t_j - t_i + (r_{jk} - r_{ik}) \times 6.18 \right| \geq \tau_R + \Delta \tag{14}$$

rearranging (14) one obtains

$$\left| (t_j + r_{jk} \times 6.18) - (t_i + r_{ik} \times 6.18) \right| \geq \tau_R + \Delta$$

and noting that t_j, t_i, r_{jk}, r_{ik} all are all nonnegative

and further that in general

$$|a - b| \geq |a| - |b|$$

(14) will always be satisfied if

$$t_j - t_i + (r_{jk} - r_{ik}) \times 6.18 \geq \tau_R + \Delta$$

Further, since $t_j - t_i > 0$ and $r_{ik} \geq 0$; $r_{jk} \geq 0$

a worst case condition occurs when $r_{jk} \equiv 0$

Thus, assume $r_{jk} \equiv 0$ i.e. aircraft j and k are coincident

so that

$$t_j - t_i - r_{ik} \times 6.18 \geq \tau_R + \Delta \tag{15}$$

Substitution of (12) into (15) yields

$$\delta \geq (r_{ik} - 2r_M) \times 6.18 - \tau_I + \Delta - T_D \tag{16}$$

Now, suppose aircraft k only requires garble free reception for aircraft within a cylinder of radius ρ and altitude $2\Delta h$ (see Figure E-3).

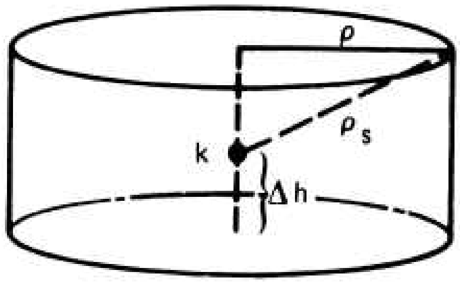


Figure E-3

Thus $\rho_s = \sqrt{\rho^2 + \Delta h^2}$ (17)

and putting aircraft i on the boundry of this zone yields the worst case. Thus let

$$r_{ik} = \rho_s = \sqrt{\rho^2 + \Delta h^2}$$

so that (16) becomes

$$\delta \geq \left[\sqrt{\rho^2 + \Delta h^2} - 2r_M \right] \times 6.18 - \tau_I + \Delta - T_D \tag{18}$$

Equation 18 guarantees that aircraft k will be garble free within a zone of radius ρ assuming aircraft outside ρ will be discriminated against on the basis of signal strength. Next consider aircraft j. For j to be garble free, it is necessary that

$$\left| t_{jk} - t_{ji} \right| \geq \tau_R \tag{19}$$

where t_{jk} is the time aircraft j hears the end of the k transmission and t_{ji} is the time aircraft j hears the end of the i transmission

Now, from (12)

$$t_j - t_i = \delta + 2r_M \times 6.18 + \tau_I + \tau_R + T_D \tag{20}$$

and by substitution of (18) into (12) one obtains

$$t_j - t_i = \rho_s \times 6.18 + \tau_R + \Delta \tag{21}$$

Now, $t_{ji} = t_i + r_{ij} \times 6.18 + \tau_R$

but $r_{ij} = r_{ik} = \rho_s$

so that $t_{ji} = t_i + \rho_s \times 6.18 + \tau_R$ (22)

Thus, from (21) and (22)

$$t_j = t_{ji} + \Delta \tag{23}$$

Let t_k = time aircraft k transmits so that

$$t_{jk} = t_k + r_{jk} \times 6.18 + \tau_R \tag{24}$$

but $r_{jk} \equiv 0$ so that

$$t_{jk} = t_k + \tau_R \tag{25}$$

Next, consider from scheduling considerations that

$$t_k = t_j \pm (\tau_R + \tau_B) \tag{26}$$

since k and j are at the same range

Substitution of (26) into (25) yields

$$t_{jk} = t_j + \tau_R \pm (\tau_R + \tau_B) \tag{27}$$

Substitution of equation (23) further gives

$$t_{jk} = t_{ji} + \Delta + \tau_R \pm (\tau_R + \tau_B) \tag{28}$$

so that

$$t_{jk} - t_{ji} = \Delta - \tau_B \qquad \text{k before j} \tag{29}$$

and $$t_{jk} - t_{ji} = \Delta + 2\tau_R + \tau_B \qquad \text{k after j} \tag{30}$$

but from (19)

$$\left| t_{jk} - t_{ji} \right| \geq \tau_R \tag{31}$$

so that if $$\Delta \equiv \tau_R + \tau_B \tag{32}$$

$$t_{jk} - t_{ji} = \tau_R \qquad \text{k before j} \tag{33}$$

$$t_{jk} - t_{ji} = 3\,\tau_R + \tau_B \qquad \text{k after j} \tag{34}$$

which in either case satisfies (19).

Therefor[illegible]itution of (32) into (18) yields

$$\delta = \left(\sqrt{\rho^2 + \Delta h^2} - 2r_M \right) \times 6.18 - \tau_I + \tau_R + \tau_B - T_D \tag{35}$$

and guarantees both k and j garble free in a zone of radius ρ . A graph of (35) over the region of interest is presented as Figure E-4.

For the case of unscheduled replies if the replies are allowed to clear the antenna, then the required buffer between calls is identical to that presented above.

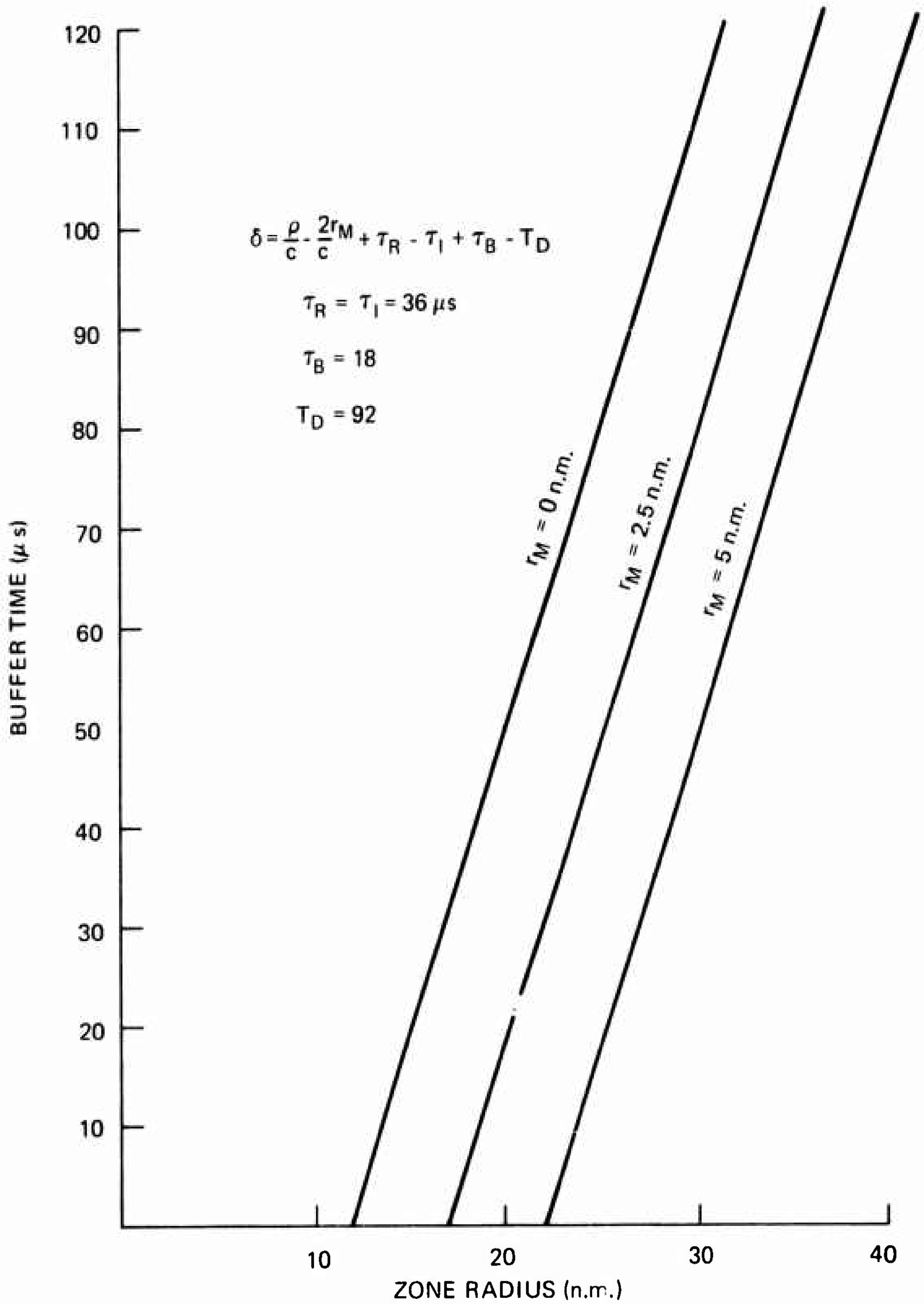


Figure E-4. Buffer Time vs. Garble Free Zone
(Replies Scheduled)

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